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AUTOMOTIVE MANUFACTURING PROCESSES
VOLUME III - CASTING AND FORGING PROCESSES

DEPARTMENT OF
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Bethesda MD

FEBRUARY 1981
FINAL REPORT

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16. Abstract
Extensive material substitution and resizing of the domestic automotive fleet, as well as the introduction of new technologies, will require major changes in the techniques and equipment used in the various manufacturing processes employed in the production of automobiles. The purpose of this report is to document (and analyze) the publically available data on current and projected motor vehicle production processes and equipment and to report on impending changes.

This report describes the specific processes and techniques used to produce cast and forged parts. The advantages of this process, the equipment and facilities required, the size of the industry, the capital requirements for a typical plant, as well as the energy and labor demands are also addressed.

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Casting, Assembly, Facilities, New Technologies, Trends, Material Substitution, Weight Reduction, Capital Investment, Equipment, Labor and Energy

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PREFACE

This report is Volume III of a series of five reports which address changes occurring in motor vehicle manufacturing processes, materials, and equipment during the period 1978 to 1980. The reports present an overview of the major manufacturing processes and materials, and a summary of historical improvements in motor vehicle fuel economy, emissions reduction, and safety. Also included are detailed discussions of vehicle components designed to improve motor vehicle fuel economy, emissions, and safety. The reports also present detailed examination of motor vehicle manufacturing process industries, trends, and issues.

The five volumes in this "Automotive Manufacturing Process" series are listed below:

Volume I - "Overview"

Volume II - "Manufacturing Processes for Passive Restraint Systems"

Volume III - "Casting and Forging Processes"

Volume IV - "Metal Stamping and Plastic Forming Processes"

Volume V - "Manufacturing Processes and Equipment for the Mass Production and Assembly of Motor Vehicles."

METRIC CONVERSION FACTORS

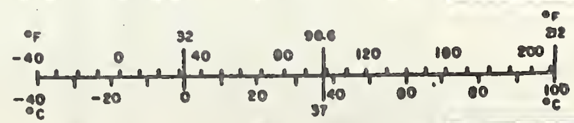
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

1.1 GENERAL

Government regulations, gasoline prices, and consumer demands are causing unprecedented modifications in the design and manufacture of automobiles. As the auto manufacturers strive to downsize and increase the efficiency of their vehicles, they are changing their requirements for materials and the processes used to manufacture automotive parts. This is having a significant impact on companies that supply materials to and perform manufacturing services for the auto industry.

For example, some metal suppliers are facing sudden increases in orders for aluminum or high strength steels. Other companies, such as iron casting suppliers, are experiencing decreases in demand for certain products. The resulting actions taken by the affected automobile suppliers can have significant impacts on the overall health of the economy and on industry, employment, material, and capital needs.

A full understanding of the effects of manufacturing changes on the economy requires a relatively detailed knowledge of the manufacturing processes and industries involved. Many important questions that are significant to the economy center on manufacturing issues. For instance:

- What segments of the aluminum casting industry appear most able to provide low cost, high quality parts to the auto industry?
- Can iron foundries economically and effectively switch to making aluminum parts?
- What are the capital costs of technical changes or new plants?
- What effect would manufacturing industry changes have on the demand for industrial equipment and industrial materials?

The answers to these specific and rather technical questions would lead to an understanding of significant general changes likely to take place in our economy.

1.2 SCOPE AND OBJECTIVES OF THIS REPORT

This report defines the techniques, equipment and capital requirements for casting and forging processes in the automotive industry. It is the third in a series of seven detailed analyses of automotive manufacturing processes and equipment. The information presented will hopefully provide the broad background and industry understanding that will aid government decision makers in evaluating the effects of changing regulations on manufacturers. The report covers the various processes and segments of the casting and forging industries that are important to automotive production. For each process, information is provided as follows:

- The mechanics of the process, process variations, and different materials involved <u>as they are used in the auto industry</u>.
- The advantages and disadvantages of the process compared to competing technologies.
- The equipment used for the technology in an automotive manufacturing environment.
- The size and structure of each industry, including major companies in the industry supplying automotive parts.
- A typical plant layout with a description of the manufacturing operation and the materials flow
- The capital requirements for a representative plant serving the automotive industry, including costs by equipment category. Labor and energy requirements are also given.
- Key issues in the industry.

The report should provide enough detailed information to allow the reader to intelligently deal with the automotive issues related to the casting and forging industries.

1.3 METHODOLOGY

The major sources of information for this report were:

- Technical journals, pamphlets, and books describing current technology

- Industry experts from the various casting and forging industry sectors and familiar with the largest auto manufacturers

- Literature from numerous casting and forging companies and discussions with many of their executives and technical personnel

- Literature from casting equipment suppliers and discussions with sales engineers and company executives.

Special effort was made to develop typical automotive plants for each of the casting and forging processes. These plants serve to clarify the technology involved, portray realistic labor, materials, capital, and energy requirements, and provide a basis to understand the specific effects of changing technology.

In addition, technical information is provided on the various processes so that plant modifications as a result of industry changes may be readily comprehensible. The relationship between the various technologies and particular automotive uses is stressed throughout the report.

1.4 ORGANIZATION

This report is organized into major sections on sand casting, shell mold casting, die casting, permanent mold casting, hot forging, and cold forging. These are the major casting and forging techniques used in the auto industry. In addition, brief overviews of forging and casting describe the organization of the industries and some of the common characteristics of the processes used.

2. AUTOMOTIVE CASTING PROCESSES

2.1 GENERAL

Casting is the process of pouring molten metal into a mold. The mold is removed when the metal has solidified and the metal piece has the form of the original mold cavity. The finished piece is also called a casting.

Casting is used widely to make automotive parts including blocks, brake drums, cylinder heads, manifolds and housings. The castings must usually be machined and then used in the assembly of automotive components.

The casting industry is one of the largest in the United States, and foundries constitute the nation's fifth largest industry based on value added by manufacturer. About 25 percent of casting shipments go to the automotive industry, annually, and castings accounted for about 17 percent of the weight of a car in 1978.

2.2 STEPS IN THE CASTING PROCESS

Although many processes are used for casting, these processes have common characteristics, as illustrated in Figure 1. During one step of the operation metal must be melted and alloyed in preparation for pouring. The melting is generally done in cupolas or electric furnaces. Another part of the plant must prepare the mold. The term mold is used to describe the material that defines the outside of the casting. If holes or passages are desired inside the casting, models of these passages, called "cores" must also be prepared. The cores are inserted into the outer mold before the metal is poured.

In the next step, the molten metal is poured into the mold. After solidification the mold is removed from the casting and the casting is cleaned. In some cases heat treatment is required. Finally the casting is trimmed and machined, although these operations may be done at a separate facility. Casting inspection also has to be carried out at various points of the production process.

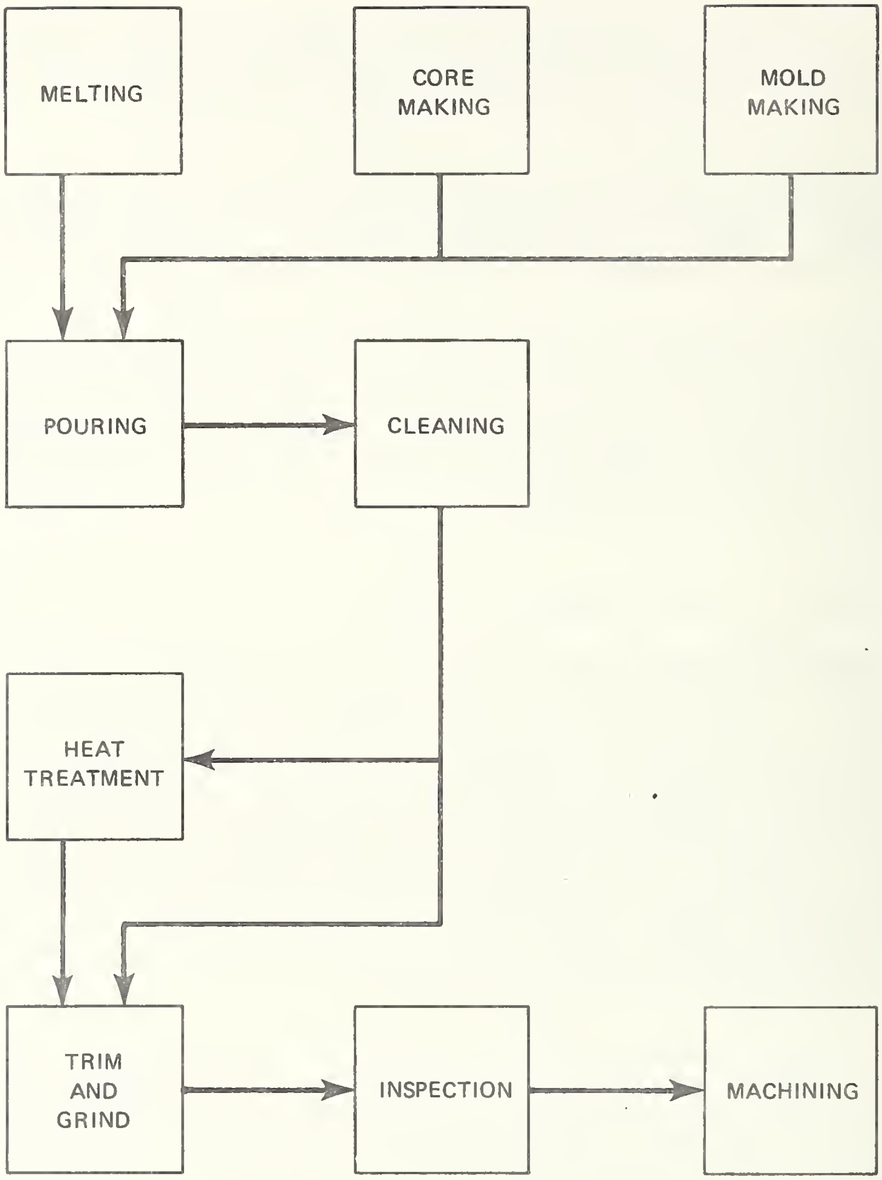


FIGURE 1
Various Steps in the Casting Process

2.3 OVERVIEW OF CASTING PROCESSES

The key operation that distinguishes casting processes is the mold construction. Several methods of categorizing casting processes are possible; one common method is shown in Figure 2.

The casting processes that are important to the auto industry are green sand molding, shell mold casting, die casting, and permanent and semi-permanent mold casting.* In this report these terms are defined as follows:

- Green sand molding uses a mold made out of compacted moist sand with clay.
- Shell mold casting uses a very thin mold made out of sand and a resin binder.
- Die casting uses a permanent metal mold and the metal is injected into the mold at high pressure.
- Permanent mold casting uses a permanent metal mold and the metal is injected into the system by gravity alone.
- Semi-permanent mold casting uses a permanent mold in a method similar to permanent mold casting, but coring is done with expendable molds made of hardened sand.

* In addition, some turbocharger blades are being made by the investment casting process. However, this currently represents a small portion of auto castings. Total domestic turbocharger sales in 1978 were 40,000.

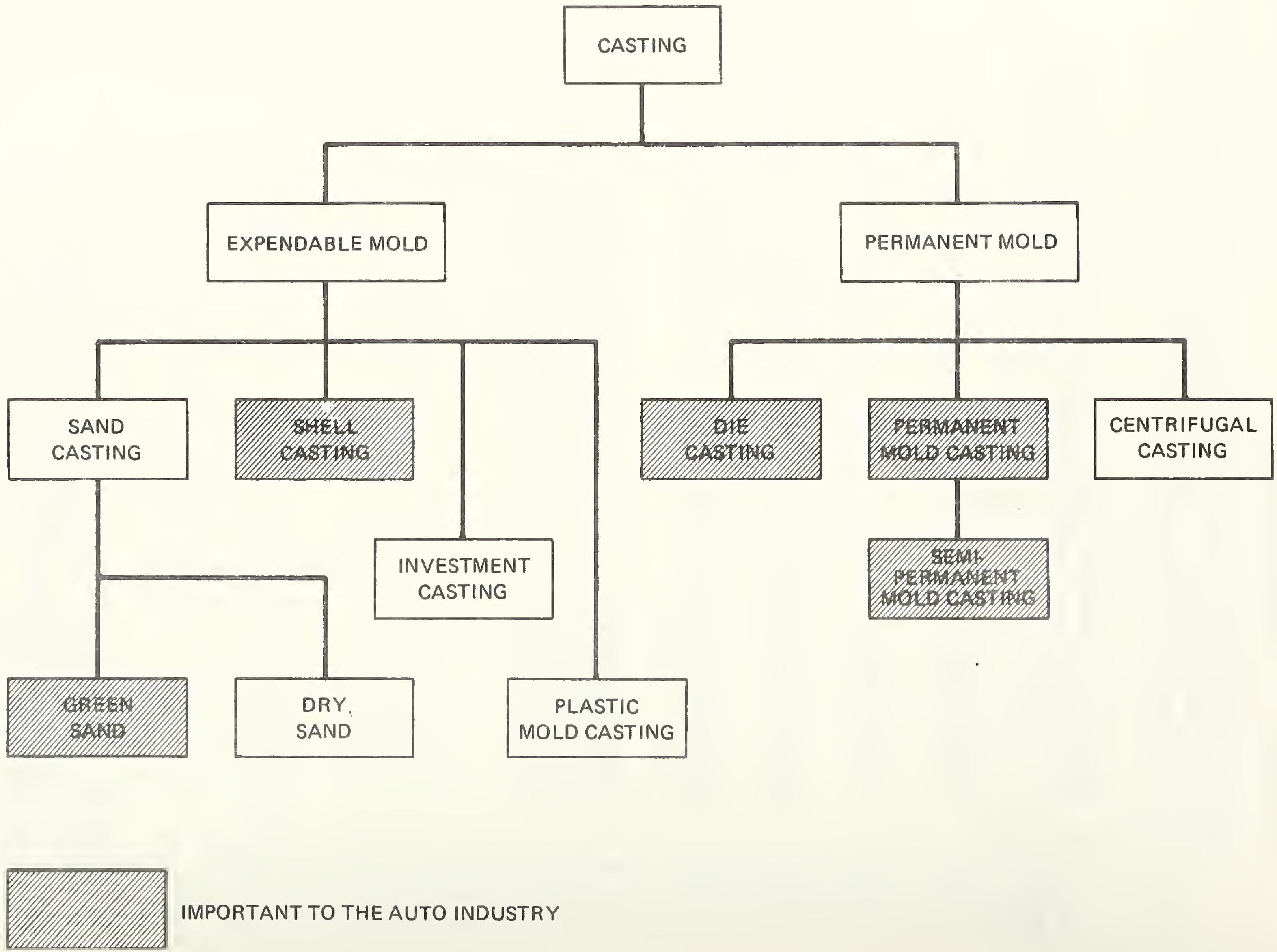


FIGURE 2
Casting Processes

3. SAND CASTING

3.1 GENERAL

Sand casting is the predominant method for casting automotive parts and components. In this casting process, expendable molds of different sands or clays are formed around a pattern into a shape. Molten metal is then poured into the sand cast and the cast is discarded after use. Sand casting can be highly automated and is often the least expensive available casting technology. Metals which can be cast by this method include iron, steel, aluminum, brass, bronze, copper and steel; iron and aluminum are the metals most often cast for automotive purposes. Automotive parts which are made via sand casting include engine blocks, cylinder heads, brake drums, calipers and rotors, and power steering housings. Sand casting use for automotive parts, however, is likely to diminish slightly as aluminum parts increase since sand casting is not expected to be the predominant process for casting aluminum auto parts.

3.2 MAJOR TYPES OF SAND CASTING

Sand castings are distinguished by:

- The type of sand used
- Molding procedures
- Types of cores
- Kinds of metals used.

Each is described below.

3.2.1 Type of Sand

There are two principal kinds of sand casting:

- Green sand molding
- Dry sand molding.

Of these two types, green sand molding is the predominant method in the auto industry.

Green Sand Molding

In green sand molding, the mold is made out of sand bonded with clay and small amounts of other materials.* The term green indicates there is moisture in the molding. When hot iron is poured into the mold the sand next to the casting is vitrified, thus providing the hard surface for the mold.

This method of casting is not suitable for large or very heavy castings. It is applicable for castings of rather intricate design, since the green sand does not exert as much resistance to the normal contraction of the casting when it solidifies as does dry, baked sand. The green sand also reduces the formation of hot tears or cracks.

Dry Sand Molding

Very large and heavy castings, not common to the auto industry, are made in dry sand molds. In this molding process, the mold surfaces are given a heat-resistant ceramic coating and are dried before the mold is closed for pouring. This hardens the mold and provides the necessary strength to resist large amounts of metal, but it increases the manufacturing time and cost.

3.2.2 Molding Procedures

A sand casting begins with a pattern of the desired shape; it can be metallic or wooden. It will be larger than the finished part, to allow for shrinkage of the metal, distortion, and machining. Patterns can be one piece or may be split into two or more parts to facilitate removal from the sand. Regardless of the type, however, the function of the pattern is the same, i.e., to imprint an image in the sand which will be the outer dimensions of the casting (before metal shrinkage).

In making the mold from a pattern, sand is packed around the pattern and hardened. As there are many different types of patterns, there are also many sand casting mold construction processes. These are known by various names such as box molding, pit molding, and template molding.

---

* Industrial molasses is a common binder in green sand molding.

Box Molding

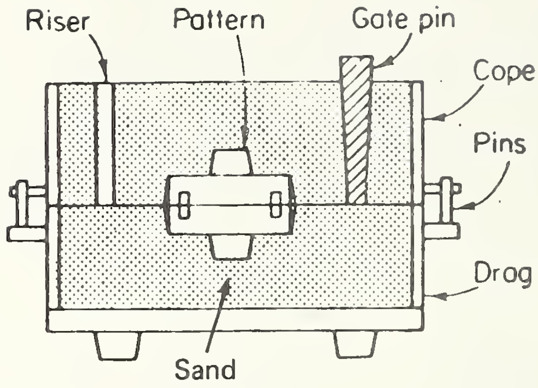
The most widely employed method for making comparatively small castings, like automotive castings, is box molding. In this method the pattern is embedded in the sand within a molding box or flask, which usually comprises an upper and a lower part, referred to in the industry as the cope and the drag, respectively (see Figure 1). The sand is compacted around the pattern by ramming, pressure or vibration. For castings of better surface finish a finer grain of sand can be packed around the pattern and then a coarser grain can be used to fill the remainder of the box. This is called backing sand. As shown in Figure 1, a gate pin is also implanted in the sand. This pin when removed will provide access to the casting through a system of channels. After the sand is hardened, the pattern parts, as well as the gate and riser pins, are removed. Cores are then inserted, and the box is closed. Thus the sand and the core form a cavity in the shape of the desired casting product (see Figure 2). Access to the casting cavity, as shown more clearly in this figure, is provided by the channels developed in the sand by the gate pin. As shown, a pouring basin which provides a larger opening may also be laid over the sprue to facilitate pouring.

After the metal is poured, it cools most rapidly where it contacts the sand. Thus the outer surface forms a shell which tends to hold its shape and pull the still-molten metal from the center toward it. The last bit of metal near the center of the mass may not be of sufficient volume to fill this remaining space, so that a partial void or porous spot will be left in the center of the casting. Those porous spots can be avoided by a reservoir or riser of molten metal near the cavity.

When the metal has solidified and cooled, the casting is removed from the mold, and the runners and risers are detached from the casting. The latter is then cleaned up by abrasive blasting, tumbling, grinding and cutting.

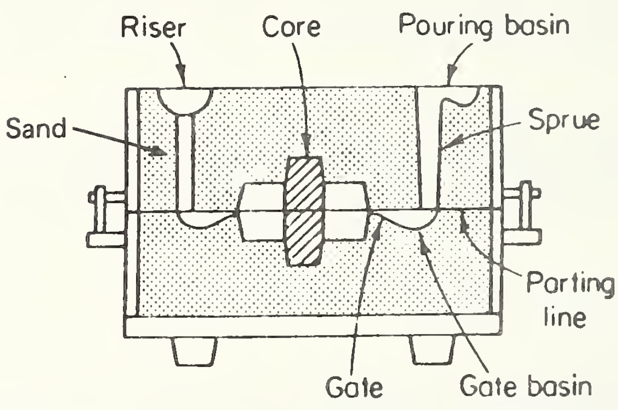
Pit Molding

For the casting of very large, heavy and intricate components the pit molding process is employed. Here the mold is built up in a casting pit. To give the sand greater strength when used as a mold material for large castings, cement may be added to it (cement-sand method). Pit molding is usually employed for parts over 100 pounds, and is therefore not widely used in the auto industry.



Source: Manufacturing and Machine Tool Operations, H. Pollack, 1968.

FIGURE 1
Sand Compacted Around a Pattern
in a Molding Box



Source: Manufacturing and Machine Tool Operations, H. Pollack, 1968.

FIGURE 2
Mold Ready for Casting

Template Molding

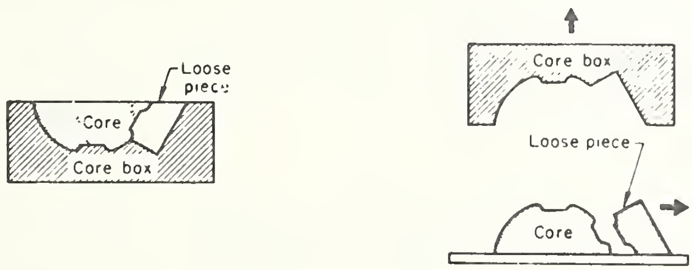
For symmetrically shaped castings the mold is sometimes formed by means of a template, a piece of metal cut to the desired profile for producing a certain shape when it is moved along a guide track or rotated on a pivot around the mold material. The process is not very precise and is thus used for non-automotive castings such as bells and pots.

3.2.3 Core Making

Cores are used to make the internal parts of castings or external additions. Cores must have the following characteristics:

- They must be formed and hardened without distortion.
- They must withstand tremendous heat shock.
- They must withstand large buoyancy forces.
- They must totally disintegrate and come out of the casting after the casting is made.

Sand is usually employed in making cores by packing it with a bonding agent. This is usually accomplished in a box with the mold for the core. The box, as shown in Figure 3, is called a core box. There are many procedures for making cores, the most important of which are discussed below.



Source: Forging and Casting, Volume 5 of The Metals Handbook

FIGURE 3
Core Made With a Core Box

Linseed Oil Process

This is an old process. Sand and a small amount of linseed oil are mixed until the sand grains are coated. The sand is then compacted in the core box, removed, and baked in an oven at 375°F to 400°F. When the casting is made, the latent heat released when the iron solidifies is sufficient to destroy the bonding of the sand. The drawback of this process is the time and cost of baking the castings.

Hot Box Process

The hot box process has been very important in the automotive industry because it allows the production of solid cores without the need for baking. The core box for this process is heated to about 500°F. The sand for the core contains a resin which hardens when the sand is placed in the heated box. This method hardens all the sand in the box and a solid core is produced.

Isocure or Ashland Process

A newer method used in the auto industry even eliminates the need to heat the core box. This is called the Isocure or Ashland process. The process employs a two-component liquid resin binder system and a gas catalyst. Basically, sand is mixed with the two liquid resin components and is then blown into a vented core box. An amine gas is blown through the core, contacts the binder on the sand, and produces an instantaneous cure to harden the core. Clean, dry air is then blown through the core to sweep out any residual amine gas.

SO_2 Process

A new core technique being used for the first time for automotive castings is the SO_2 process. It is similar to the Isocure process in that the resin in the core is hardened under the presence of a gas, in this case, sulfur dioxide (SO_2). The process does not require heat and results in less distortion than the hot box process. The SO_2 gas is also not toxic, unlike the amine gas used in the Isocure process.

3.2.4 Metals Used

Gray iron is the most commonly sand cast iron and comprises over 50 percent of automotive castings by weight. Malleable iron, ductile iron, and aluminum are frequently sand cast and are also important in automotive work.

Gray Iron

Gray iron solidifies with flakes of graphite in the metal which gives it its characteristic gray color. The iron has the ability to solidify with only slight shrinkage. Thus gray iron can be cast relatively easily into complex shapes and cavities. In addition, gray iron has the following important characteristics:

- The graphite flakes provide a surface that holds lubrication. The metal is thus very machinable and extremely wear resistant.
- The metal has high thermal conductivity and thus is better as an engine block than ductile iron because of better engine cooling.
- Gray iron is relatively brittle.
- Gray iron has high vibration absorption.

Malleable Iron

Malleable iron is a cast alloy rendered tough and ductile through controlled heat conversions. The annealing* takes from 30 hours to 6 days. The graphite precipitates inside the casting as lumps of flakes. There is a 5 1/2 percent decrease in volume as the metal cools and thus the metal is difficult to cast.

Malleable iron's important beneficial characteristic is its good ductility and good machinability. It is used in parts that must bend rather than break, such as safety and brake parts.

---

* Annealing is the process of heating and slow cooling to achieve a softer material.

Ductile or Nodular Iron

In ductile iron graphite precipitates as spheroids. The production of ductile iron castings involves complex metallurgy, the use of special melting stock, and close process control. The metal is relatively new and has found many applications because of its ductility, high degree of elasticity, and high strength. Automotive parts include disc brake parts and steering gear housings.

Aluminum

Aluminum can be sand cast in much the same manner as the various irons. The major difference in the foundry would be a different melting system. Aluminum sand castings have good productivity rates but are not made to the fine tolerances of permanent mold castings or die castings. Aluminum castings are often about a third of the weight of the same casting made in iron.

3.3 ADVANTAGES AND DISADVANTAGES OF SAND CASTING

Some advantages of sand casting are as follows:

- It is the least expensive method of producing a mold.
- There is less danger of hot tearing of castings than in other methods.
- Dimensional accuracy is good.
- Flasks (molding boxes) are ready to reuse in a minimum of time.
- The molds are strong and can accommodate a several hundred pound casting in a mold flask.
- Sand can be reused.

Some disadvantages of sand casting are:

- Sand control is critical; moisture and chemical composition must be continuously monitored.
- Sand erosion can destroy a casting.

- Surface finish deteriorates as the weight of the casting increases.

- Dimensional accuracy decreases as the weight of the casting increases.

- Production is slow.

- Air pollution is high where sand molds are used; silica dust causes silicosis.

- Sand reclamation is expensive.

- Cleaning of castings is expensive.

3.4 AUTOMOTIVE APPLICATIONS OF SAND CASTING

Many key components of the automobile, such as engine blocks, cylinder heads, intake and exhaust manifolds, and transmission and chassis components, are cast metal products. Parts made from sand casting are described below for each major metal used in automobiles.

3.4.1 Gray Iron

Gray iron is used for car parts that require good damping characteristics (such as blocks) or good wear characteristics (cylinder lining, brake drums), or for parts that do not have high loads or malleability requirements and where weight saving does not justify a lighter aluminum component. Figure 4 shows gray iron sand castings on an automobile.

3.4.2 Malleable Iron

Malleable iron parts on automobiles are used where malleability is required. These parts must withstand large forces without breaking. Automotive parts include brake calipers, universal joints, yokes, automatic transmission parts and suspension parts. Figure 5 shows malleable iron castings on an automobile.

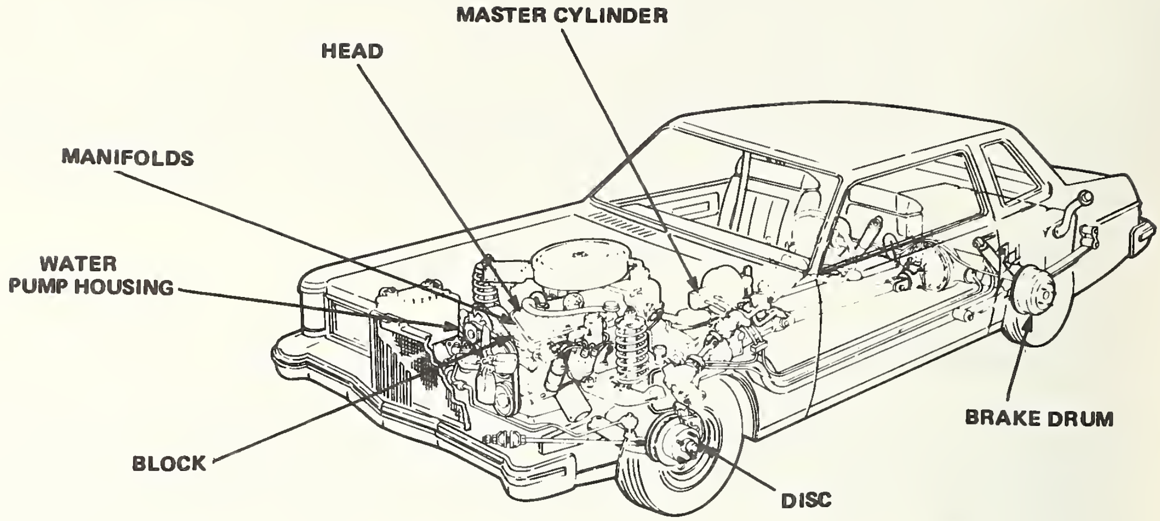


FIGURE 4
Gray Iron Sand Castings on an Automobile

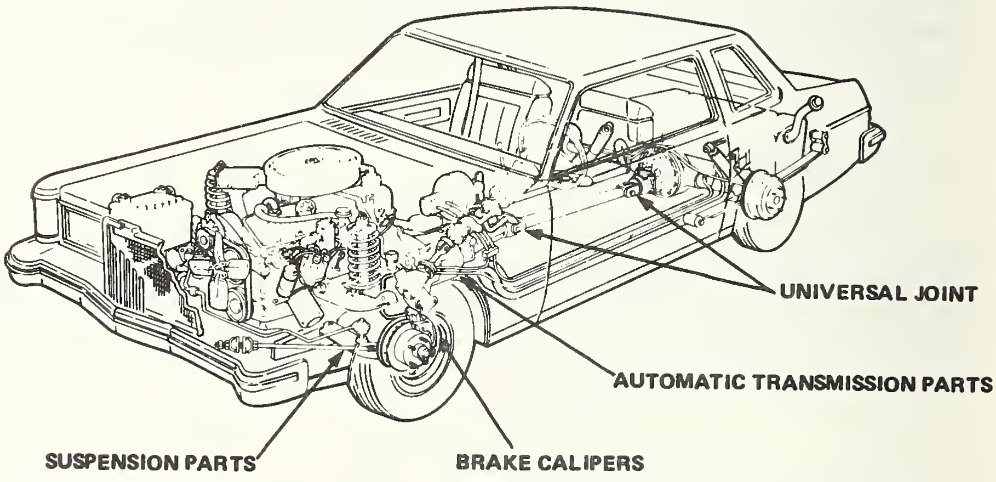


FIGURE 5
Malleable Iron Sand Castings on an Automobile

3.4.3 Ductile Iron

Ductile iron parts are used where strength or ductility is needed. Disc brake calipers, automatic transmission parts, differential carriers and cases, front knuckle castings, and steering gear housings are all made of ductile iron in at least some automotive models. Figure 6 shows the ductile iron parts on cars.

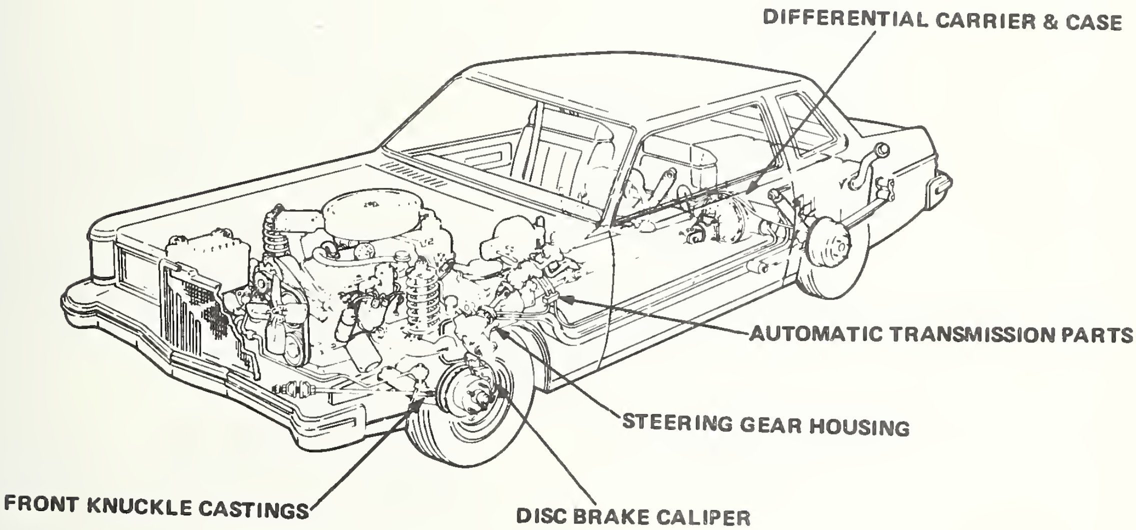


FIGURE 6
Ductile Iron Sand Castings
On An Automobile

3.4.4 Aluminum

Aluminum sand castings are now used for intake manifolds and they have potential for use in heads and other automotive parts. (See Figure 7.) However, because of slower production rates, poorer tolerances, and inability to produce thin-wall castings, future use of sand casting for aluminum is expected to be small compared to the use of other aluminum casting processes.

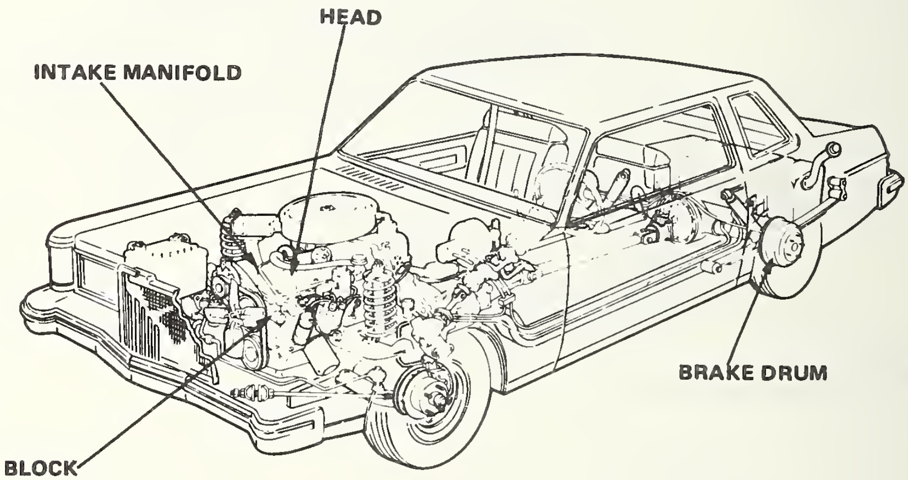
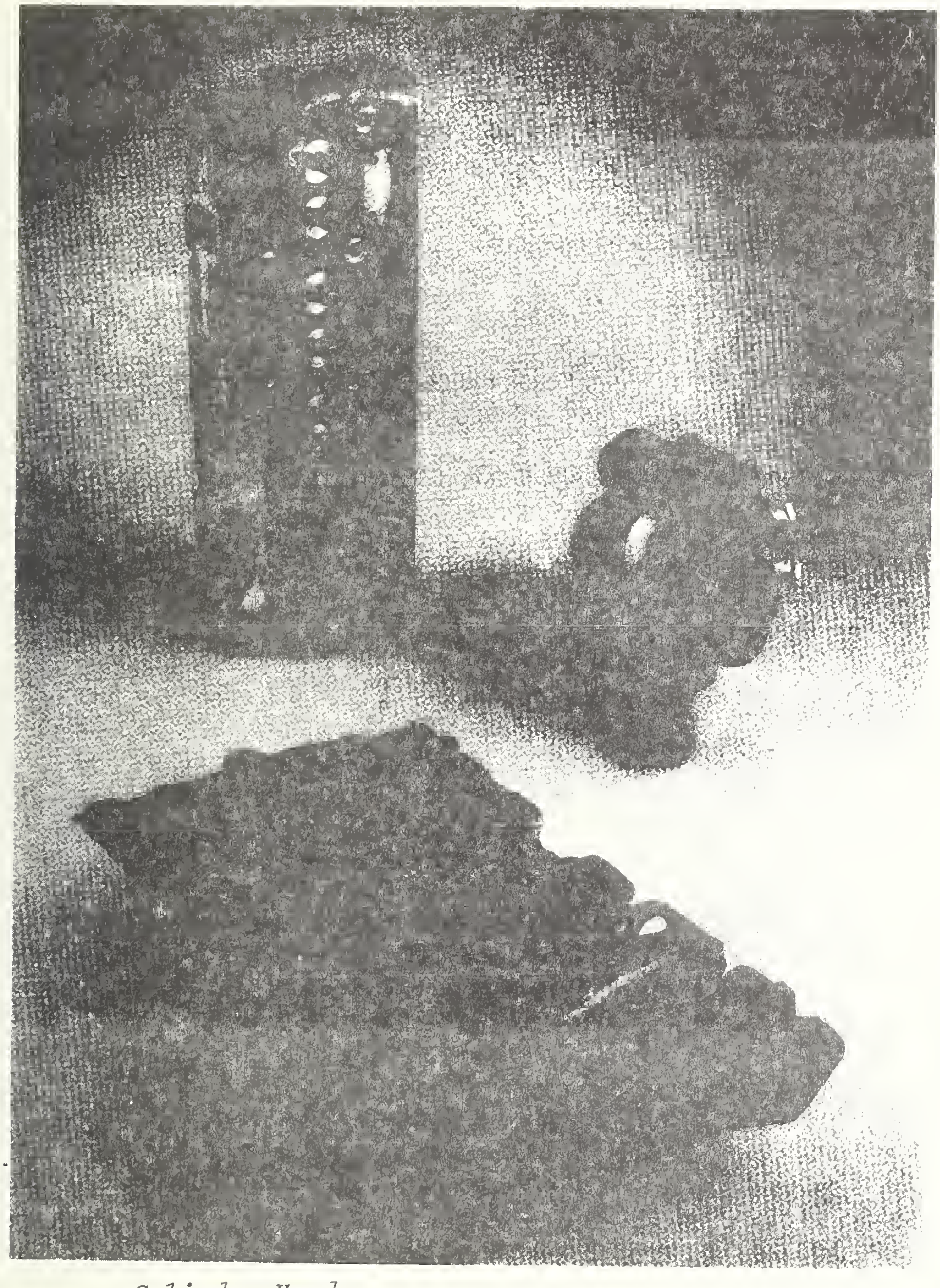


FIGURE 7
Potential Automotive Uses Of
Aluminum Sand Castings

Figure 8 presents photographs of some sand cast automobile parts.



Camshaft

Cylinder Head

Water Pump Housing

Intake Manifold

FIGURE 8
Selected Examples of
Sand Cast Automobile Parts

Source: General Motors Central Foundry Division and CWC Textron

3.5 EQUIPMENT REQUIRED

Principal categories of equipment used to manufacture sand castings are:

- Furnaces for melting metal and for keeping it molten
- Automatic machines used to make the sand molds
- Machines used to make the sand cores
- Sand mixers and transportation equipment used to recycle sand through the foundry
- Cleaning equipment used to clean the casting
- Heat treating furnaces to anneal the castings
- Ancillary equipment.

3.5.1 Furnaces

Melting of the metal (iron or aluminum) in a sand foundry can be accomplished using several types of furnaces including cupolas, arc melting furnaces and induction furnaces. The choice of furnace is based on several factors:

- Economy, including the cost of fuel per pound of melted metal and the initial cost of equipment plus installation and maintenance expenses
- Temperatures required
- Quantity of metal required per shift and per hour
- Ability of the melting mediums to absorb impurities
- Method of pouring.
- Air pollution requirements.

It is not uncommon, however, to find more than one type of furnace being used in a sand foundry.

TABLE 1
Foundry Equipment for Sand Casting

Equipment	Manufacturers	Capacity	Cycle Time	Lead Time	Price
Cupolas	Whiting, Modern Equipment	15 ton/hr 22-25 ton/hr 30 ton/hr 45 ton/hr 100 ton/hr		6-12 months	$968,000[1] 1,500,000[1] 1,880,000[1] 1,990,000[1] 5,800,000[1]
Electric Induction Furnaces	Inductotherm, Ajax Magnethermic Lindberg, and Whiting Corp.	5 ton/hr 6 ton/hr 10 ton/hr 19 ton/hr		5-9 months	275,000[2] 300,000[2] 475,000[2] 900,000[2]
Arc Melting Furnaces	Lectromelt, Pullman Swindell	10-15 ton/hr 25 ton/hr 40 ton/hr		10-12 months	600,000[3] 700,000- 800,000[3,4] 1,000,000[3]
Holding Furnaces	Inductotherm, Whiting	50 ton 25 ton 10 ton			400,000 212,000 150,000
Jolt Squeeze Automatic	S.P.O., Osborn	36"x52" Flask 19"x38" Flask 36"x52" Flask	300/hour 300/hour 300/hour	12 months	4,000,000[5] 3,800,000[5] 1,000,000[6]
Flaskless Molding	Disamatic, Sutter, and Beardsley & Piper	20"x24"	300/hour		1,200,000
Core Making	Osborn, Herman, Sutter, and Beardsley & Piper	30"x40"	1,000 cores/ hour		100,000
Muller	Beardsley & Piper	25 ton/hr 300 ton/hr		18-20 weeks	57,000 290,000
Sand/Resin Mixing (Reclaimer)	Beardsley & Piper	15 ton/hr			150,000
Tumbleblast	Wheelabrator-Frye, Carborundum Co.	75 ft^3/hr 225 ft^3/hr			130,000 370,000
Heat Treating (Annealing) Furnace	Sunbeam	8 ton/hr 8 ton/hr		25 weeks 28 weeks	380,000[7] 440,000[8]

1. Includes pollution equipment. For installation, add 100%.
2. Includes power transformer and water system, but no pollution equipment.
3. Does not include pollution equipment.
4. Pollution equipment around $1,000,000 extra.
5. Full system but not including flasks or conveyor.
6. Molding machine only.
7. Car bottom, batch-type furnace, installation $200,000.
8. Continuous-type. Installation $100,000.

Cupolas

Cupolas are the predominant method of melting metal in foundries although predominance is decreasing partly due to the large expense to control pollution from these furnaces. Cupolas provide low cost rapid melting but do not have the close temperature control of induction furnaces. Thus a cupola is often used with an induction furnace so that in combination, the foundry can have low cost melting and close temperature control.

Cupolas range in size from a melting capacity under 15 tons per hour up to 100 tons per hour. Large captive automotive foundries often have furnaces that melt 30 to 50-tons per hour, though some large commercial foundries that supply the auto industry may also have smaller size cupolas.

The major cupola manufacturers include Whiting Corporation, Harvey, Illinois; and the Modern Equipment Corporation. The price of a 30-ton per hour cupola is $1,880,000; an installed 45-ton per hour cupola could cost $4,000,000, including $1,000,000 worth of pollution equipment. Table 1 gives further details on cupolas and all other types of sand casting equipment discussed in this section.

Electric Induction Furnaces

Electric induction furnaces are also very important in foundry work. These units can maintain precise temperature control which is important for some iron uses.

Induction furnaces are often used with preheating units that warm scrap iron before it is melted. These furnaces are also often used in addition to cupolas or in conjunction with large holding furnaces that keep the metal warm after it is melted. This allows melting to be done at off-peak hours when electrical rates are lower.

The furnaces tend to be available in smaller sizes than cupolas but cost about the same per melt capacity (see Table 1). Air pollution equipment generally costs less than for cupolas. Major manufacturers of induction furnaces include Ajax Magnethermic Corporation and Inductotherm Corporation. Prices vary according to size as shown in Table 1.

Electric Arc Furnaces

Electric arc furnaces provide a high intensity energy source for melting iron. These furnaces produce melted iron in batches rather than continuously and thus are often operated in conjunction with holding furnaces. This equipment is especially efficient with cold iron. Major manufacturers include Lectromelt Corporation and Pullman Swindell. A 10- to 15-ton per hour furnace is approximately $600,000. An electric arc furnace is illustrated in Figure 9.

Holding Furnaces

Holding furnaces are used to keep iron molten after it has melted. The furnaces serve at least three functions:

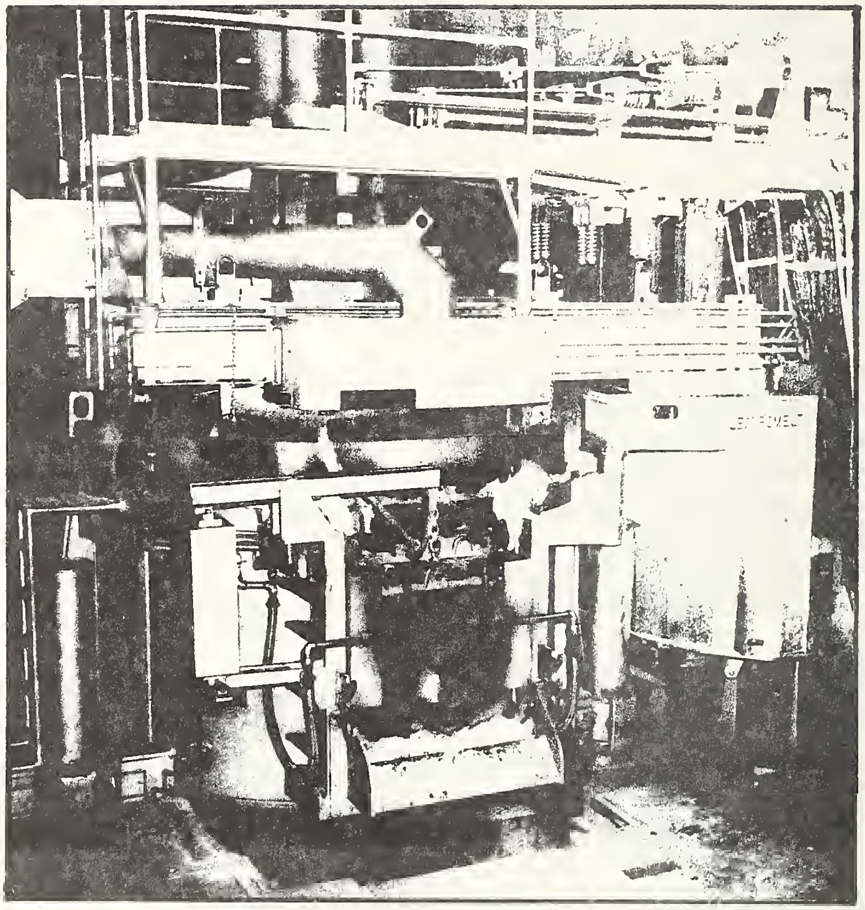
- They even out the flow of metal from the uneven production of furnaces.
- They provide metal holding capacity in the event of molding equipment breakdown.
- They allow the melting operation to be done at a different time from the pouring operation.

The size of these furnaces varies greatly depending on foundry set-up. A furnace used to even out metal flow may need only be large enough to hold a half-hour's worth of the molten metal. On the other hand, a furnace used to hold metal melted at off-peak hours to save electricity costs may be required to hold eight hours' worth of melted metal.

Most holding furnaces use electric induction. Two major manufacturers are Inductotherm and Whiting Corporation. A small (10-ton) holding furnace by Inductotherm is priced at $150,000. Table 1 gives further information.

3.5.2 Molding Equipment

Molding equipment used in large automotive foundries is usually highly automated. Two principal types of molding equipment are now used: jolt-squeeze equipment, and automatic flaskless machines.

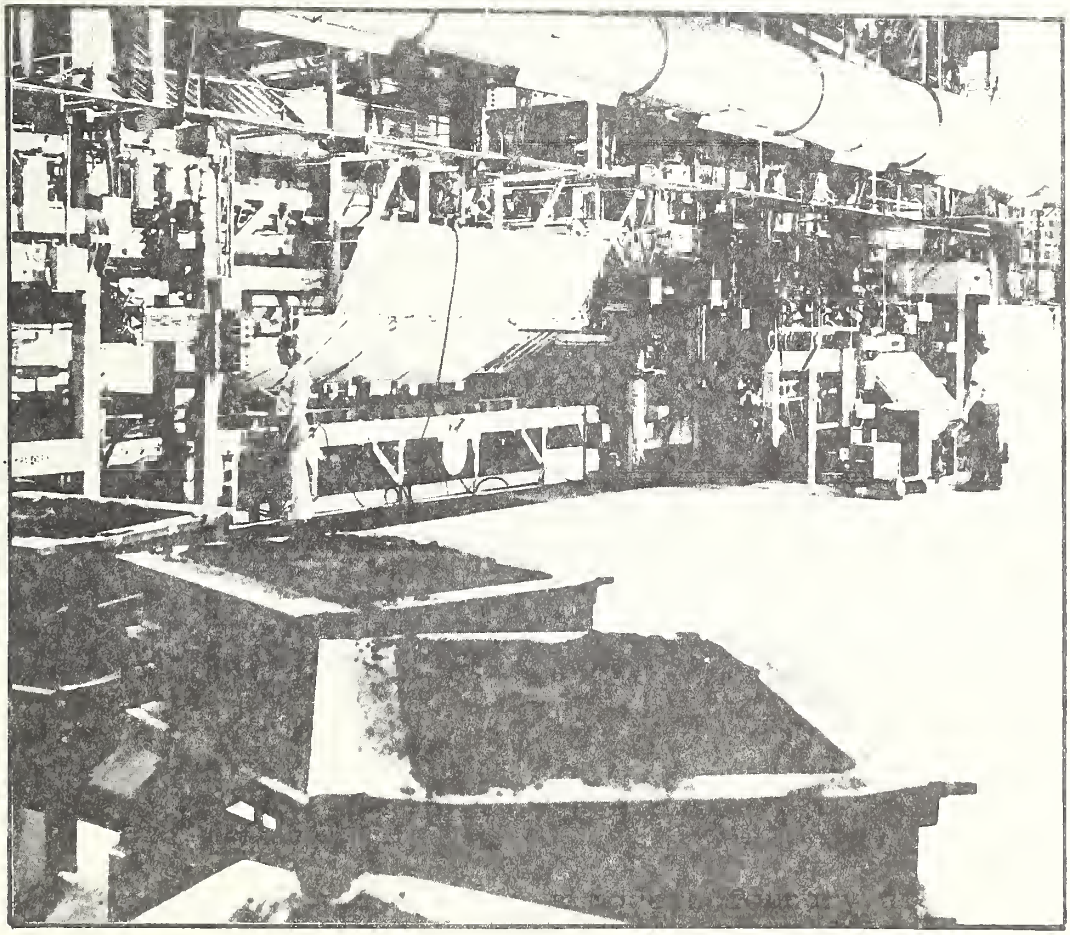


Source: Lectromelt Corporation

FIGURE 9
Electric Arc Furnace

Jolt-Squeeze Machines

Jolt-squeeze machines in a modern foundry are highly automated versions of the green sand box molding technique described earlier. Hundreds of standard size flasks are used. The flasks move on conveyors and the mold machinery automatically sets the patterns, packs the sand, and transports the flasks. (See Figure 10.) Hundreds of feet of conveyors associated with the mold lines carry the castings through the molding, pouring and cooling areas. The term jolt-squeeze refers to the way the sand is compacted around the pattern; jolting refers to lifting the mold and dropping it, causing the sand particles to compress together; squeezing applies to compaction through pushing the outside of the sand.



Source: Lynchburg Foundry

FIGURE 10
Automatic Sand Molding Jolt-Squeeze Equipment

Jolt-squeeze machines are sized according to flask size. Typical sizes are 24"x24"x18" (top and bottom) and 36"x52"x24" (top and bottom). Manufacturers of automated jolt-squeeze molding systems include S.P.O. and the Osborn Manufacturing Corporation. The S.P.O. system is priced at $4,000,000. Table 1 gives details of this and other molding systems.

Automated Flaskless Molding Equipment

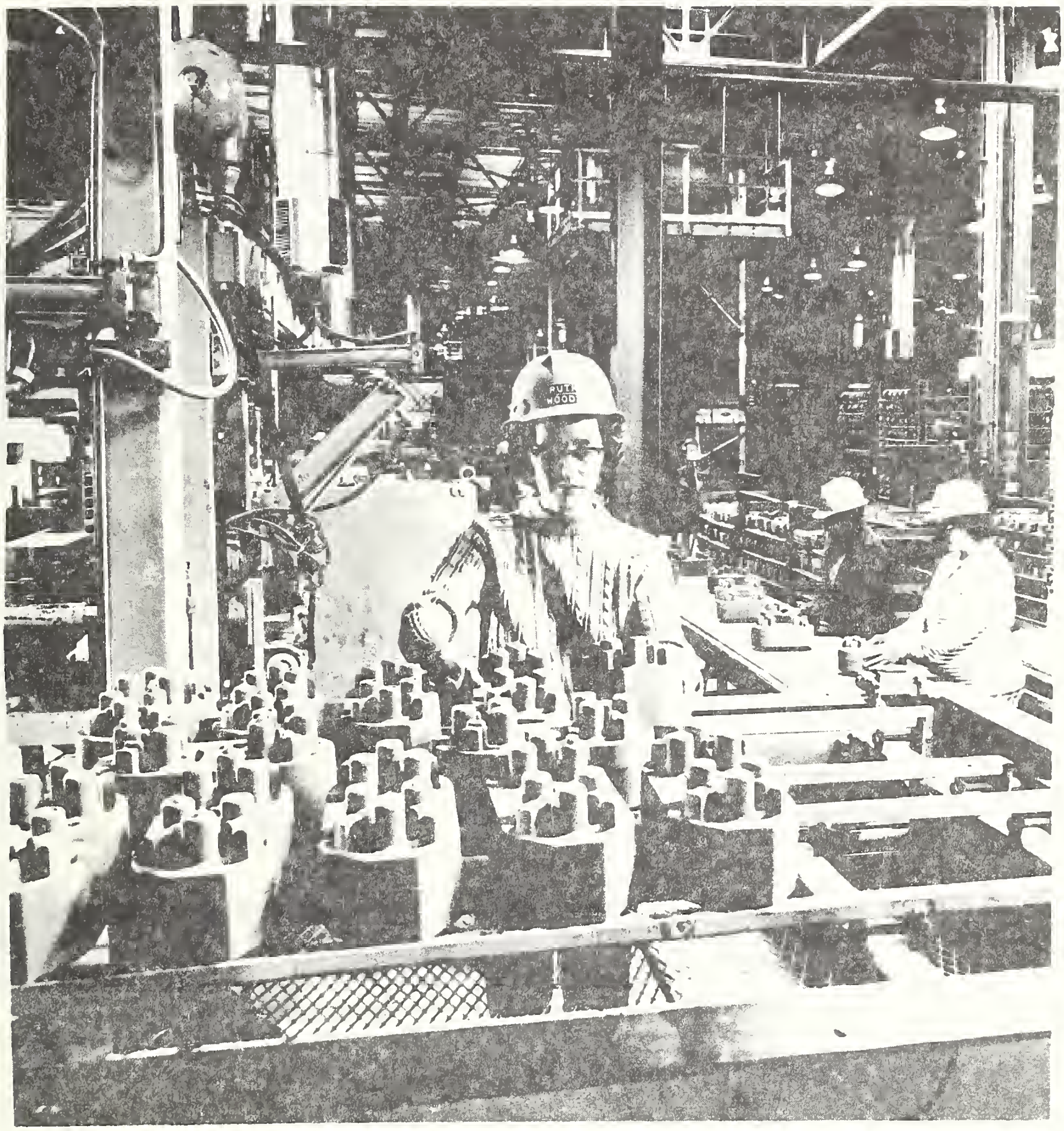
A new type of molding system does not use flasks, but makes the mold within the machine. These systems are fast but are somewhat less flexible than flask systems. Otherwise the systems are similar. Disamatic, Inc., Hinsdale, Illinois, has been the most successful maker of flaskless moldmaking machines. Other manufacturers include Sutter, and Beardsley and Piper. The system manufactured by the latter is $1,200,000. Table 1 gives details.

3.5.3 Coremaking Machines

Automated machines also now exist to make cores. The cores are made separately from the molding machine apparatus and are usually installed by hand along the molding line. The cores can thus be made by a group of machines in a separate core room and then transported to the molding line by conveyors.

Core machines usually have longer cycle times and less output than large molding machines. The number of cores needed in an operation is determined by the number of cores in a single casting and the number of castings produced in an hour. Each core making machine can make a different number of cores per hour depending on the size of the cores being used. (See Figure 11.)

Core machines that use gas processes for core hardening require gas collection or pollution equipment. In addition, the core room requires a machine to mix sand with resin and numerous conveyors to transport the cores.



Source: Lynchburg Foundry

FIGURE 11
Core Making

Core machines are generally made by the same people who make molding machines such as Sutter and Osborn, and the cost of the machine by Osborn is $100,000. Table 1 gives more information on core machines.

3.5.4 Sand Equipment

Sand transport and recycling is an important part of foundry operation. The key parts of the sand system include:

- Shakeout where the sand is separated from the finished castings
- Reclamation where part of the sand is cleaned and separated
- Mixing or mulling where the sand is mixed with water, clay, and new sand so that it has the necessary properties for good castings
- Cooling
- Return conveyors and bins
- Distribution system.

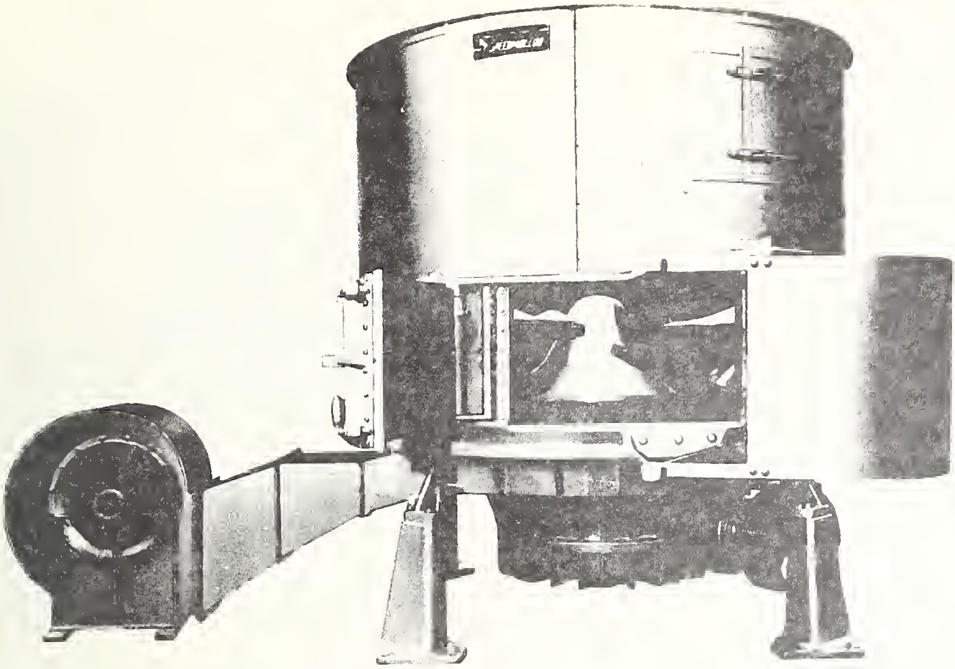
Reclamation and cooling are optional operations. Cooling is required depending upon the type of parts produced and the sand to metal ratio in the flasks. To cut down on the amount of new sand which must be added to the operation, 15 to 25 percent of the sand is often put through a reclaimer. The reclaimer separates out broken sand particles or sand lumps and returns the sand to near new condition.

Major manufacturers of sand equipment include Beardsley and Piper and Jeffrey Manufacturing Division, Dresser Industries Inc. Figure 12 shows a high-speed muller manufactured by Beardsley and Piper. A 25-ton per hour muller costs $57,000; a 300-ton per hour machine costs $290,000. Further information is given in Table 1.

3.5.5 Cleaning Equipment

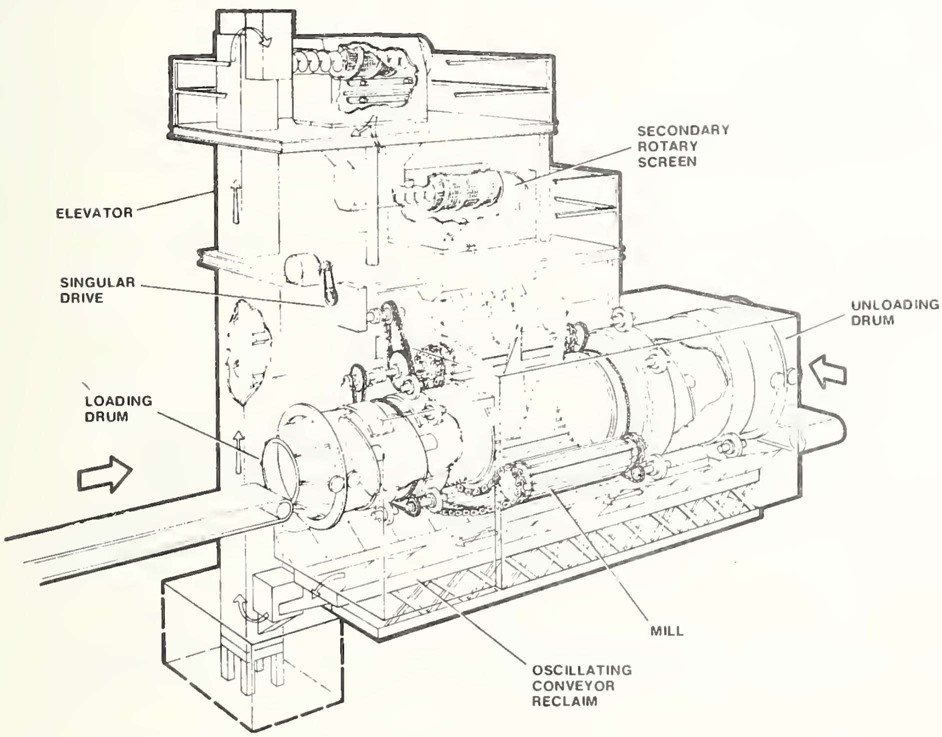
Cleaning equipment is used to remove residual sand from the castings, grind away major metal protrusions, and knock off or saw off gates and risers.

The equipment used to remove residual sand is usually one or several shot blast machines. (See Figure 13.) Major manufacturers of these devices include Wheelabrator-Frye, Inc., and the Carborundum Company. These machines are sized by the cubic feet of iron parts that can be processed per hour. A 75-cubic foot per hour machine costs $130,000. See Table 1 for details.



Source: Beardsley and Piper

FIGURE 12
A High-Speed Muller



Source: Wheelabrator-Frye

FIGURE 13
Blasting Machine

3.5.6 Heat Treating Equipment

Many iron castings (especially those of malleable or ductile iron) require heat treating prior to shipment.* The furnaces are rated by hourly tonnage, and they operate either as batch-type or continuous operations. Automotive plants could use either type of operation. Batch furnaces are approximately 15 percent cheaper than a continuous furnace, but have drawbacks such as difficulty of loading and high fuel costs. Continuous furnaces use less fuel and are easy to load. In addition these furnaces are better suited to tempering. Installation cost for a large batch furnace would be significantly higher than for a continuous furnace.

The furnaces for heat treating are available with either gas or electric heating. Gas is currently cheaper to use but since its supply has fluctuated many companies are installing gas furnaces with options for adding electric heating.

The cost of heat treating furnaces varies with the type of heat treat cycle desired and the number of castings to be treated each hour. An 8-ton per hour furnace costs about $400,000. Table 1 presents more information.

3.5.7 Ancillary Equipment

Foundries will use other pieces of equipment depending on their particular needs. Examples include:

- Conveyors needed to move the castings after shakeout to cooling, cleaning, or heat treating areas.
- Pattern maintenance and flask repair machinery.
- Laboratory equipment. Foundries must be able to control sand composition, measure precise dimensions, and test the quality of castings. Very large foundries use X-ray and radiographic equipment for non-destructive testing of finished products.
- Raw materials handling equipment such as storage bins, scales, and cranes
- Ladles and pouring equipment.

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* This is done primarily to relieve stresses from cooling and to refine the crystalline grains to make the castings more machinable.

Manufacturers of this equipment include Beardsley and Piper and Jarvis Webb. Cost of this equipment would vary according to the foundry layout, sophistication of laboratory techniques, and the volume of materials handled by the plant.

3.6 SIZE AND STRUCTURE OF THE SAND CASTING INDUSTRY

Sand casting is the largest of the casting industries consisting of both iron and aluminum foundries. Of the 4,829 ferrous and non-ferrous foundries, 3,412 have sand casting capabilities. In the iron segment of the industry, the sand casters are predominant in both high-volume and low-volume applications in many industries. Specific figures on sand casting tonnage as a percent of total iron casting tonnage are not available, but industry sources have said that iron castings are overwhelmingly sand castings, and the tonnage of castings made by other processes is very small.

In the aluminum segment, sand casters tend to be smaller than die casters and permanent mold casters. In addition, sand casting aluminum is not a growing market and only comprises 10 percent of all aluminum casting tonnage. Die casting accounts for 67 percent of the tonnage and 23 percent is permanent mold. Figure 14 presents a diagram of the casting industry as described above. Details on the two segments of the industry (iron casting and aluminum) are provided below.

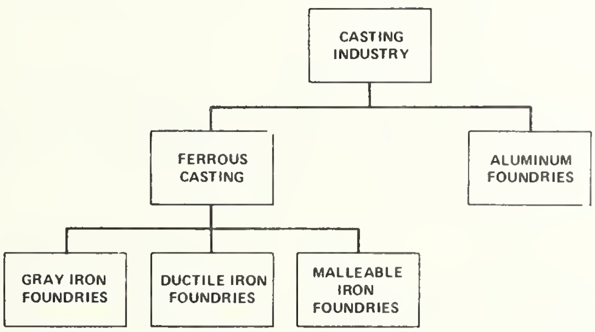

FIGURE 14
Automotive Casting Industry Segmented by Major Metals Used

3.6.1 Iron Casting Segment

As shown in Figure 14, iron foundries are often divided by the type of metal cast. Sand casting is predominant for all the metals used—gray iron, ductile iron, and malleable iron. In 1977 gray iron accounted for approximately 77 percent of all iron cast, or 64 percent of all casting shipments. (See Table 2.) In 1978 there were approximately 1,416 gray and ductile iron foundries and 56 malleable iron foundries. About 90 percent of these employed less than 250 people.

The iron casting industry is presently undergoing significant change. Tonnage shipped has remained relatively steady over the past ten years, yet the number of establishments has dropped significantly. The foundries that have gone out of business have mostly been small facilities unable to cope with changing technology or pollution and safety regulations. Many larger foundries have been expanded and modernized. The Department of Commerce and some foundry spokesmen forecast continued growth in the castings market over the next five years.

TABLE 2
1977 Casting Production

METAL	NET TONS (Millions)	PERCENT OF TOTAL
Gray Iron	12.5	64
Ductile Iron	2.7	14
Malleable	.8	4
Steel	1.7	9
Non-ferrous	1.6	8
TOTAL	19.3	100

The Automotive Iron Sand Casting Market

The automotive market is extremely important in the iron casting industry. The foundries that are part of General Motors, Ford, and Chrysler contain by themselves approximately 20 percent of the casting capacity of the entire industry. General Motors alone has hundreds of casting suppliers.

The automobile industry annually consumes approximately 25 percent of gray iron casting production, 55 percent of ductile iron castings, and 65 percent of malleable iron casting production.

Iron sand casting is very important to the automobile. An estimated 90 percent of auto castings are iron and about 92 percent of these are made through sand castings. The balance is mostly shell mold castings.

Captive Foundries

Foundries that are owned by corporations and make castings predominantly for that corporation are termed "captive" foundries. Foundries that supply to outside customers are termed "commercial" foundries.

In the auto industry each of the major manufacturers owns foundries. These foundries make high-volume parts. General Motors Corporation owns 24 foundries with a total annual capacity of 3.1 million tons. Ford Motor Company owns six foundries with a 1.8 million ton capacity. Chrysler Corporation has five foundries capable of making .6 million tons of castings a year. General Motors is considered to have a greater in-house casting capacity relative to its needs than the other car manufacturers. However, all the car manufacturers have a large amount of castings done by commercial foundries outside the auto industry. Estimates on the amount of automotive castings done by the commercial foundries range from 20 to 50 percent of total automotive casting tonnage.

Major Commercial Automotive Iron Foundries

There are an estimated 550 to 600 commercial foundries that have a considerable amount of business with the auto industry. However, the number of major foundries is perhaps a tenth as much. Table 3 lists some of the major commercial iron foundries that supply the auto industry.

3.6.2 Aluminum Segment

Sand casting aluminum accounts for 205.4 tons, 10 percent of total aluminum castings. However, sand casting is the primary casting method for about two-thirds of the small independent foundries. Sand casting is not the growth part of the aluminum casting market. Captive operations and die casting have been growing instead. Many of the smaller aluminum sand casters will be making aluminum replacement parts for automobiles. But there is also room for growth in the original equipment market (OEM).

TABLE 3
Major Automotive Iron Foundries

Company	Monthly Iron Casting Production Units	Percent to Auto Industry
Lynchburg Foundry	25,000	50
Dayton Malleable	22,500	more than 30
Wheland	19,600	90
CWC-Textron	17,000	25
Hayes-Albion	16,000	75
Waupaca	12,000	
Brillion	8,800	
Eaton Corporation	6,500	
Auto Specialties	5,400	
Columbus	5,000	50

Source: Cast Metals Federation and Company Statistics.

The Automotive Aluminum Sand Casting Market

Until recently aluminum automotive parts were made by die casting. These parts include transmission housings, windshield wiper housings, and other parts traditionally made from aluminum.

Sand castings have been used to some extent for the production of the newer aluminum parts—manifolds, heads, etc. An estimated seven or eight sand casters now supply aluminum castings to the auto industry. Intake manifolds presently being sent to the auto industry are about 50 percent sand cast and 50 percent permanent mold cast.

Major Automotive Aluminum Sand Casters

None of the auto companies have built, or are expected to build, sand casting facilities for aluminum. The largest sand caster of aluminum for the auto industry is Cast Metal Industries Inc. The company, which makes 8,000 manifolds per day, expects the proportion of aluminum manifolds that are sand cast to decrease to 20 to 25 percent of the market as cars are downsized. This is because the smaller, less complex four-cylinder engine manifolds may lend themselves to die casting and welding. More complex manifolds may still be sand cast as well as some heads. Cast Metal Industries has recently built a major aluminum sand casting facility in Wabash, Indiana. The other major automotive aluminum sand caster is Metaloy in Hudson, Michigan.

Sand casting leads to higher production rates than permanent mold methods, but initial investment is higher. However, sand casting tolerances are not as close as permanent mold castings. Presently, General Motors seems to be favoring sand casting and Ford is tending more toward permanent mold castings.

3.7 TYPICAL PLANT

As described in the last section, commercial suppliers of sand castings to the auto industry are predominantly large automated foundries that for the most part produce gray or ductile iron castings. More insight into typical commercial automotive foundries can be gained with the aid of Table 4. This table shows important statistics and the major parts produced at many automotive-oriented foundries. One can see that a plant with a net capacity of 60,000 to 80,000 tons per year and employing 700 to 900 people would be a representative auto foundry. Typical parts would be small—carriers, calipers, or housings. Although many variations of foundry construction and operation exist, the following sections present some of the expected features of such a representative foundry.

TABLE 4
Automotive Iron Foundries

Company	Plant	Number of People	Net Capacity (Tons)	Parts	Irons
Hayes-Albion	Tiffin	600	100,000	Drums, Calipers	Gray
Dayton Malleable	GHR	800	120,000	Transmissions Parts	Gray
CWC-Textron	Sherman	337	36,000	Camshafts	Gray
CWC-Textron	National Motor Castings	331	28,000	Manifolds	Gray
Hayes-Albion	Albion	1,450	100,000	Differential Housings, Yokes	Ductile & Malleable
Dayton Malleable	Ironton	1,000	90,000	Calipers	Ductile
Lynchburg	Archer Creek	1,000	75,000	Carriers, Cases	Gray & Ductile
Ausco	St. Joseph	(700)	40,000	Carriers, Cases	Malleable
Ausco	Riverside	(450)	25,000	Carriers, Cases	Malleable
Columbus	Columbus	1,000	50,000	Knuckles	Ductile

3.7.1 Plant Layout

Figure 15 shows a diagram of the typical plant. The major areas of the plant include:

- The melting area
- Sand preparation and molding
- The core room
- Shakeout and cleaning room
- Pattern shop
- Tool room
- Quality control area.

The Melting Area

The melting area comprises the cupolas, holding furnaces, minirail and pouring stations. The quality of iron pouring and the maintenance of pouring rates is the responsibility of this area. First the proper ratio of cupola

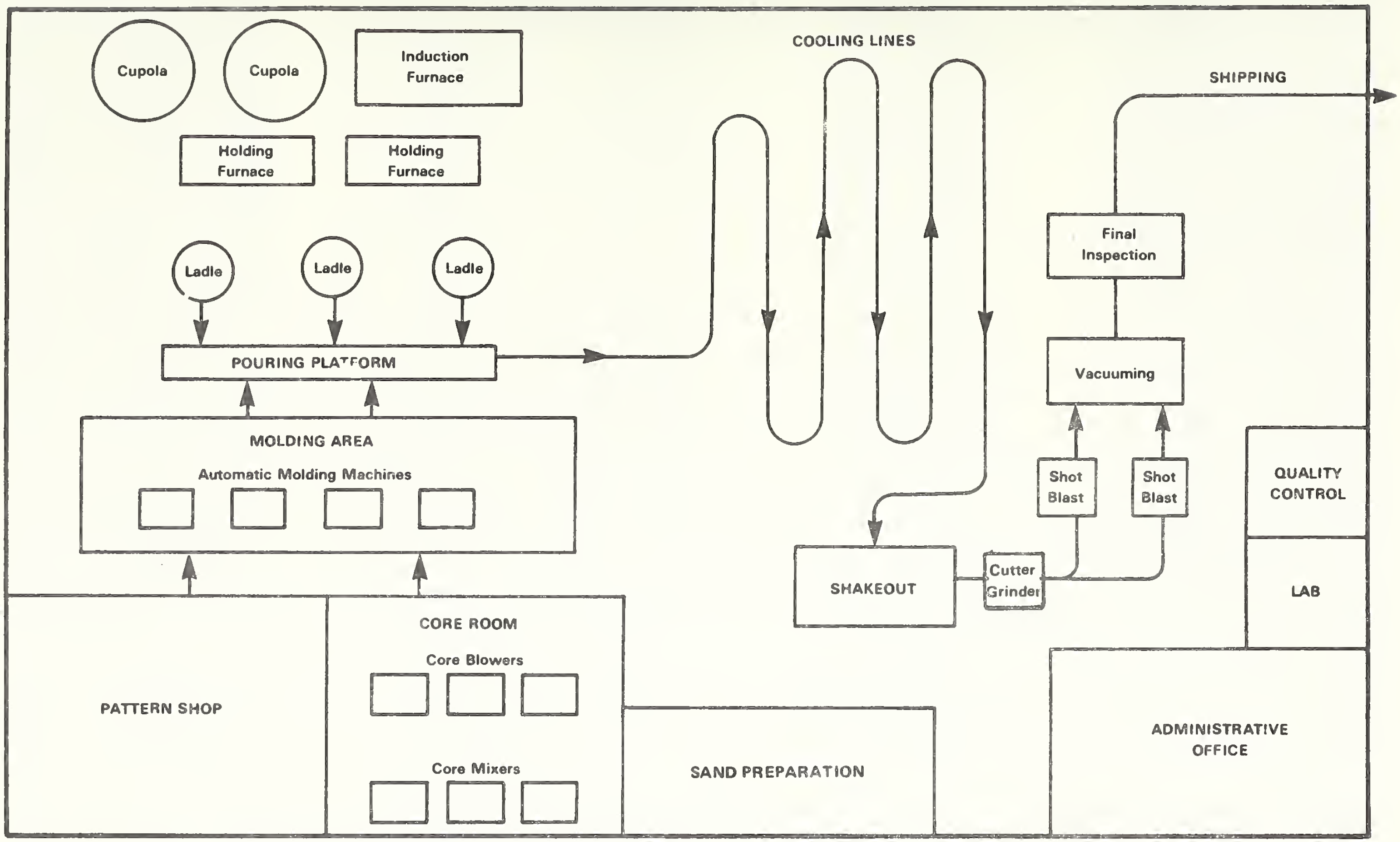

FIGURE 15
Typical Sand Casting Plant Layout

input components must be selected from the storage yard. These are placed in a cupola charge bucket and then dumped into the cupola. Normally the charge consists of different grades of scrap iron and metallurgical grade low sulfur coal. Molten metal then runs out at a typical rate of 20 to 40 tons per hour into holding furnaces where the metallurgy is checked. If subsequent additions are required they are placed into the pouring ladle just before pouring into the sand molds. A minirail which is an overhead monorail device carries molten metal from the holding furnaces to the ladles on the pouring line.

Sand Preparation and Molding

In the sand preparation area, sand for molding and core use is carefully graded to size and consistency. Binders such as clays and powdered coal are added. In the molding area, the sand, after it is checked for quality, is packed around a pattern inside a flask on the automatic mold making machines.

The Core Room

Within the core room a series of critical events take place. First, resin must be selected and diluted with water or alcohol. Then it is mixed in mullers with core sand, which is of a special consistency quite different from molding sand. The sand, impregnated with resin, is then injected into cavities in core blowing machines. In more modern machines the cores are cured in the "hot box." Older systems had to have special ovens to cook the cores. Once completed, the cores are shipped to the mold assembly line for insertion in the flask cavity to form future "holes."

Shakeout and Cleaning Room

After the cores and molds are assembled and the iron has been poured, it takes about 30 to 45 minutes for the molten metal to solidify so it can be broken away from the flask and retain a shape. Sometimes the metal casting is still glowing hot. The castings cool while they move on conveyors and then proceed through shakeout where most of the sand is removed. Often it is necessary to saw apart the sprue, gate, and runner systems from the part itself. The scrap iron is recirculated through the system while the good parts are shaken vigorously on a metal screen table, the sand falling through the screening. The good parts are sent to the cleaning room for shot cleaning of surface scale and sometimes vacuuming of internal sand out of the core. Once the parts are cleaned they are palletized and sent to shipping where they are placed on trucks for shipment to machining plants. The shakeout area is an exceptionally noisy, hot, and dusty place to work; some foundries double-man the area allowing one-half hour on and one-half hour off the job.

Pattern Shop

Patterns can be custom made for each part in the pattern shop. Small foundries may not be capable of making their own patterns although the large ones sometimes can. The patterns are made by skilled artisans using various castings and machining techniques. The accuracy of castings depends largely upon accurate pattern construction.

Tool Room

The tool room is necessary to machine parts and to repair all the existing machinery in the plant. Standard machines such as a lathe, milling machine, and drill press can be found in such a room. In addition, some pattern cutting operations may also take place in the tool room.

Quality Control

Random parts are selected and taken to the Quality Control Department where dimensional checks are made on specially made jigs and fixtures. Samples of metal are sectioned, polished, and etched to check the microstructure for the proper graphite form.

3.7.2 Materials Flow

Principal materials which are handled in a sand casting foundry include iron scrap, sand, and resin materials. The flow of each type of material through the plant layout illustrated in Figure 15 is given below.

Iron

Iron is received usually in the form of scrap and stocked outside the foundry. It is put into the cupola where it is melted and then stored in the holding furnace. The metal is poured into the sand molds and cools to become the rough casting. After shakeout, gates and risers are removed. This metal, along with scrapped parts, is recycled back to the cupola. The good castings are cleaned and shipped.

Sand

New sand is brought in from the outside to the sand preparation area. It is mixed with old sand and checked for proper moisture and clay content. The sand mixture is then transferred to the mold making area where it is used to make the molds. Sand is removed from the casting at shakeout and is transferred back to the sand preparation area. Some of the sand is reclaimed (up to 25 percent) where it is cleaned and separated and returned to nearly new condition. This is necessary to maintain the quality of the castings. The reclaimed sand and the other recovered sand is mixed with new sand in preparation for further mold making. About 5 to 10 percent of the sand is lost through each cycle and is made up by the new sand.

Resin

Resin is used in the coremaking process. It is mixed with core sand in the core room. The cores travel with the castings,and the core sand generally becomes part of the recycled green sand mixture. The resin is not recovered.

Typical Materials Requirements

In general the sand use is five to ten time the per hour iron poured by weight. Thus a foundry pouring 30 tons per hour of iron may need 300 tons of sand per hour. Most of this is recycled although some is lost, and new sand equal to about 10 percent of the sand requirements is added each day.

Iron use will be slightly more than the output tonnage of the plant. Output tonnage varies as a percent of poured tonnage. In general output tonnage as a percentage of poured tonnage is 60 to 65 percent for gray iron and 50 percent for malleable or ductile iron.

Resin needs depend on the amount of coring. Resins usually account for about 2 percent of core sand by weight.

Thus, a typical automotive foundry operating two shifts and making 15 tons of good castings per hour using 15 tons per hour of core sand would use the following materials each day:

- Iron - 240 tons
- Sand
  - New - 480 tons
  - Reclaimed - 4,320 tons
- Resin - 5 tons.

3.7.3 Capital Requirements

To develop capital requirements, we will again assume a typical automotive foundry pours 30 tons per hour, yields 17 tons of good castings per hour, makes small (about 5 pounds) high-volume automotive parts requiring cores, is highly mechanized, and operates two shifts.

A rule of thumb employed in the foundry industry puts the costs of a modern captive auto foundry at $1,200 per yearly ton of output. Pouring 30 tons per hour with a 55 percent yield means the casting output is about 60,000 tons per year. Thus the foundry would cost a maximum of $72 million. An actual commercial foundry would tend to cost less than this because it would be less sophisticated and require less equipment than a captive shop.

Capital requirements for a foundry include building and land requirements and equipment requirements.

Building and Land Requirements

A foundry requires 5 square feet per ton of output. Thus, a 300,000 dquare foot building would be required. See Table 5 for building and land costs.

TABLE 5
Building and Land Requirements

Capital Requirement	Cost
Building (300,000 square feet @ $80 per square foot)	$24,000,000
Land	3,000,000
TOTAL	$27,000,000

Equipment Requirements

Equipment requirements can be segmented into the areas listed below. See Table 6 for an itemized list of equipment costs.

- Melting Equipment - To melt 30 tons of metal an hour would require a cupola capable of this melt rate for each shift. Each full cupola system would cost about $3.9 million installed for a total of $7.8 million. A holding furnace capable of holding a half hour's melt would be necessary. This would cost about $250,000 installed.

- Molding Equipment - The automatic molding equipment usually operates at around 300 cycles per hour. At a pouring rate of 30 tons an hour, each flask would receive about 200 pounds of metal and about ten times as much sand or a ton of sand per flask. To handle the necessary volume of sand, either large flasks could be used or three molding lines, each operating with smaller flasks. For small parts, the latter would be more convenient because of lighter flasks and because of easier accessibility. The cost of the smaller system would be around $4 million plus 15 to 18 percent for installation.

TABLE 6
Capital Equipment Costs of a 30-Ton Per Hour Sand Cast Iron Foundry

Equipment	$ (Millions)
<u>Melting</u>	
Two cupolas, 30 ton/hour, installed	7.80
Pouring system	0.50
Holding furnace	0.25
<u>Molding</u>	
Molding equipment, installed	4.70
Conveyor	2.00
<u>Core</u>	
Core machines	1.20
Resin mixing	0.20
Other core support	1.10
<u>Sand System</u>	
Muller	0.35
Other sand equipment	2.90
<u>Cleaning Area</u>	
Wheelabrator	0.45
Other cleaning equipment	3.00
Other	1.00
Lab	0.70
Heat treat equipment	0.54
Raw material handling	0.25
TOTAL	$27.00

- <u>Core Equipment</u> - Approximately 10,000 cores must be made per hour. Ten machines would typically be needed. When the costs of resin-sand mixers, conveyors, and other core room support equipment are added, the total core equipment cost is around $2.5 million.

- <u>Sand System</u> - The sand system includes shakeout, sand mixing, and sand delivery. Such a system costs $11,000 per ton of sand in use. With a pour rate of 30 tons an hour, approximately 300 tons of sand is in use. Thus the sand system should cost around $3.3 million.

- Other Costs

  - Lab for $.7 million. This does not include expensive X-ray equipment found in large foundries.

  - Heat treat furnace, capable of annealing 8 tons per hour in a continuous fashion, $440,000 plus $100,000 for installation (for ductile iron).

  - Raw materials handling equipment, $250,000. This includes storage bins, scales, and cranes.

  - Cleaning equipment, $3.5 million. This includes a Wheelabrator tumbleblast capable of handling 76 cubic feet of castings an hour, grinders, and saws.

  - Other equipment, such as conveyors, pattern and flask maintenance equipment, and cafeteria facilities.

3.7.4 Labor Requirements

As discussed earlier, a foundry producing 60,000 tons of castings per year would likely employ 600 to 800 people. A rough breakdown of the employees is given in Table 7.

3.7.5 Energy Requirements

An arc furnace will need 450 to 500 kilowatt hours to melt a ton of iron. Induction furnaces and cupolas tend to use 10 to 30 percent more power because they are generally less efficient furnaces. However, if the metal is preheated,

TABLE 7
Labor Requirements for Two-Shift Sand Casting Plant

Skill	Number
Administrative and Skilled, including:	100
• Plant manager	
• Department managers, quality control, production, accounting, manufacturing engineering, industrial engineering	
• One metallurgist and staff of 20 specialists	
• Sand and resin technologists	
• Pattern makers	
• Tool and die makers	
• Melting technologists	
• 20 foremen	
Unskilled, including:	
• Shift 1 production workers	300
• Shift 2 production workers	300
TOTAL	700

the induction furnace becomes significantly more efficient. Table 8 shows the efficiences of various furnaces. Using the figure of 700 kwh per ton to melt iron, the foundry melting 30 tons per hour would be using 21,000 kw of electricity for melting. The holding furnace would use another 3,000 kw of power (about 150 kw per ton).

Compared to these figures, other energy costs would be small. The large automatic molding machine would use a maximum of 500 horsepower or 650 kw to operate. Lighting power usage would also not be significant.

TABLE 8
Furnace Efficiencies

Furnace	Meltdown Efficiency (%)	Superheat Efficiency (%)
Cupola (Water-cooled, hot blast)	30-60	5
Induction Furnace	70	70
Arc Furnace	80	20-30

Heat treating costs would add an estimated 2 percent. Thus the total foundry energy consumption excluding heatings would not greatly exceed the furnace energy use of approximately 25,000 kw or 830 kwh per ton of poured metal. Heating costs would depend upon the geographic location of the plant.

3.8 KEY ISSUES

Major issues currently confronting the sand casting industry include:

- Changing technology. The industry is increasing ductile iron production as a substitute for gray and malleable iron.
- Changing markets. The auto industry downsizing and lightening of cars is leading to smaller castings and changes from iron to aluminum castings.
- Competition from overseas.
- Capital shortages.

3.8.1 Changing Technology

The major auto manufacturers have increasingly switched to ductile iron for many of their parts. As a result, foundries with a capability in ductile iron have seen substantial growth in their business. Other foundries have been forced to buy the new equipment needed to produce ductile iron and to learn the technology and production methods needed to produce these castings. Malleable iron foundries have had a particular problem with this changing technology since ductile iron is in many cases the preferred substitute to malleable iron. In terms of the typical plant, ductile iron production requires annealing furnaces and alloying equipment not always needed for gray iron. The rest of the foundry remains virtually the same. However, the difficulty with making ductile iron is not particularly associated with large capital investments but with the precise metallurgy and operating procedures required to produce good parts. Thus foundries entering the ductile iron market must gain experience and master new operating technology.

3.8.2 Changing Markets

Changes in the auto industry are having important impacts on the foundry industry. The conversion of certain auto parts to aluminum has caused a decrease in gray iron sales for some companies, especially those producing parts that have been converted to aluminum, such as intake manifolds.

There is some disagreement within the foundry industry about the extent to which downsizing of parts by itself creates excess foundry capacity. Smaller parts imply less metal and it is thus reasonable that there should be excess melt capacity. However, other factors in a foundry also determine its capacity to make auto parts. The number of parts that fit into a flask will determine the capacity of the molding equipment. If parts are not downsized sufficiently to increase the number of parts in a flask, a foundry will not be able to increase its output without investing in more facilities. In addition, smaller parts still require cores and grinding. Thus, part downsizing does not necessarily increase total foundry capacity. However, given that significant sections of plants become underutilized, capacity should increase as plants try to better utilize their facilities either by producing different parts or making selected capital expenditures.

Some companies have claimed that as a result of industry excess capacity caused by downsizing the captive auto foundries have taken a greater share of casting production to the detriment of the jobbing foundries. Other foundries, especially those that produce ductile iron or produce parts that have not been downsized or switched to aluminum, report no impact from auto industry changes. The entire foundry industry is estimated to currently be operating at 70 percent of rated capacity.*

There is a question whether the large captive foundries would assume a greater share of total auto foundry purchases if there were excess industry capacity due to auto downsizing. The captive foundries are large and tooled up for the components requiring high volumes. The jobber foundries tend to be more specialized and more susceptible to change. For instance, Dayton Malleable continues to sell automotive air conditioning castings and CWC-Textron continues to sell camshafts to General Motors because the companies are able to produce the parts at less expense or with superior characteristics than GM's foundries.

Since the future of aluminum in sand casting appears limited, increasing auto industry usage of aluminum parts may further reduce sand casting tonnage. Sand casting will probably be used for large aluminum parts requiring cores in complex arrangements. Die casting will likely be used for most aluminum parts due to its lower cost, better finish, and thin-wall production.

It is also unlikely that aluminum parts for which sand casting is the chosen casting method could economically be sand cast in foundries that presently do iron casting. Such a switch from iron production to aluminum production would require major changes in the melting and cleaning areas of the foundry. In the typical plant presented earlier, these parts of the foundry constitute about 20 percent of the entire capital cost of the plant, and about 40 percent of this amount was for installation. Thus a foundry would have to see a tremendous potential for aluminum sand casting before undertaking such a costly change. Sand foundries have virtually no capability to change over to aluminum permanent mold casting or die casting since the equipment is different throughout the processes.

3.8.3 Competition From Overseas

Many foundries have found that some of their products are now being made overseas and sold at lower prices than the American foundries can charge. Castings are being imported from Japan, Brazil, and Europe. The castings are reportedly of good quality. Price has been cited as the

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* American Metal Market, April 21, 1978, page 6A.

principal reason for losing out to imports, even if quality had to be compromised. Although imports have affected the sales of foundries that serve the auto industry there have not been any reports of major auto companies purchasing castings from overseas.

3.8.4 Capital Shortage

A study by the Cast Metals Federation has indicated that due to predicted expansions, modernizations, and pollution abatement expenditures, the entire casting industry could need as much as $10 billion from 1978 through 1981 for capital expenditures. Further, 18 percent of the capital necessary will have to come from unknown sources.* The study indicates that low selling prices in the industry have resulted in inadequate returns to generate the capital needed. This is particularly a problem with smaller foundries.

* American Metal Market, April 21, 1978, page 3a.

4. SHELL MOLD CASTING

4.1 GENERAL

The shell mold method of producing castings is basically an extension of classic plaster molding. In plaster molding, the pattern made of metal or plastic is surrounded by a paste of gypsum plaster which is removed when it has set and is then assembled to form the mold which will receive the metal. With plaster it is possible to make molds of high precision, but this material has the disadvantage of having low permeability to gas, which may give rise to difficulties in casting. This drawback can be overcome by the addition of foaming agents which increase the porosity of the plaster.

Shell mold casting essentially makes a hard mold out of sand instead of plaster. The process was invented by Croning and patented in 1944. Its principle consists of making a thin sand "shell"—only a few millimeters thick—around a pattern and then assembling the parts of the shell to form the mold for the metal. A suitable mold material is a mixture of 95 percent fine quartz sand and 5 percent synthetic resin and a hardening agent. Alternatively, a sand whose grains have been precoated with a resin may be used, the advantage of this technique being that segregation of the material is thereby prevented.

Gray and ductile iron are the two metals most commonly shell mold cast for automotive purposes. Automotive parts which are made via shell molding include cams, crankshafts, exhaust valves and transmission parts.*

4.2 MAJOR TYPES OF SHELL MOLDING

Like sand castings, shell mold castings are distinguished by:

- The type of molding materials used
- The molding process employed
- Cores used
- Metals used.

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* The terms "shell mold casting" and "shell molding" are used interchangeably.

4.2.1 Materials

In the auto industry only sand is used for shell mold casting, but different resins can be applied, and different sand-resin mixtures can be used. The sand-resin formulations will vary widely depending upon the alloy, pouring temperature, and type of casting.

Phenol-formaldehyde resins are the most commonly used in shell mold casting, because when combined with sand, they have high strength, resistance to heat and moisture, and good flowing and curing properties.

4.2.2 Molding Processes

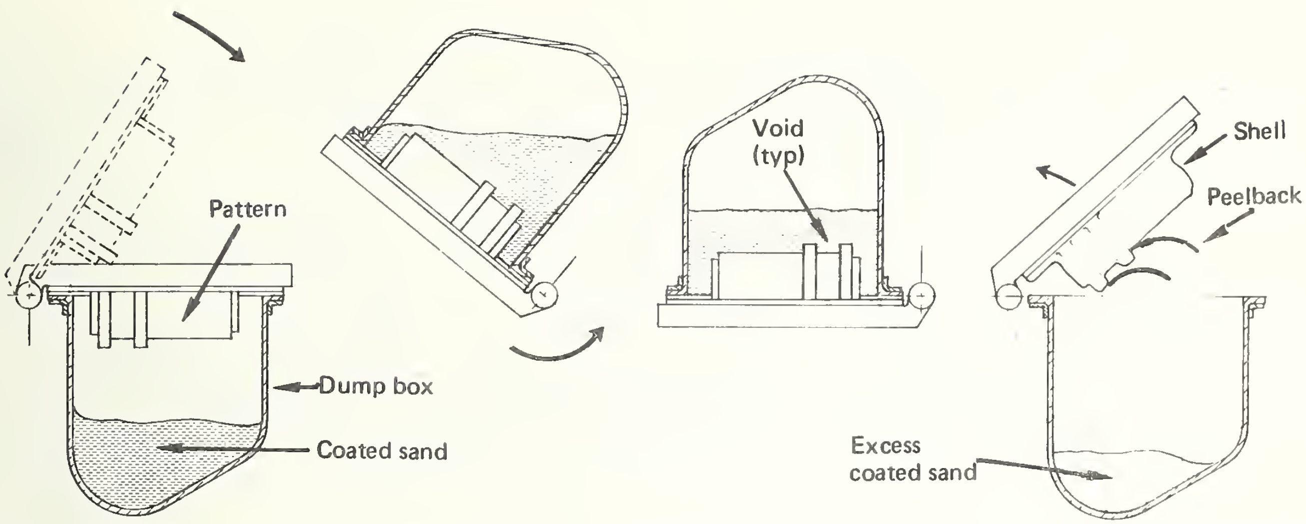
The principal components of shell mold casting are similar to those of green sand molding. They include patterns, sprues, risers, runners, gates, ejector pins, and sand strips or rims.

Shell mold patterns generally do not differ in design from patterns for green sand molding. However, because of slowed metal solidification in shell molds (caused by the lower moisture content), it is sometimes necessary to increase the size of the pattern slightly to compensate for shrinkage.

There are several molding procedures used to make shell molds. These include the dump box and blown shell techniques, both of which are used by the auto industry.

Dump Box Technique

In the dump box technique, the resin-sand mixture is placed over a heated pattern, by means of a dump box. (See Figure 1.) In this process, the amount of the mixture is considerably greater than that needed to form the shell to ensure that the pattern is completely covered. Pattern temperature settings are gauged according to the intricacy of the pattern, the weight of the mold required, and the type of resin-sand mixture being used. The temperature settings may vary from a low of 400°F to a high of 650°F. The resin adjacent to the pattern melts, causing the mixture to adhere to the pattern. The portion of the mixture that adheres to the pattern is called the investment, and hence the operation is called the investment cycle.



(a) Pattern rotated and clamped to dump box (b) Pattern and dump box rotated (c) Pattern and dump box in position for the investment (d) Pattern and shell removed from dump box

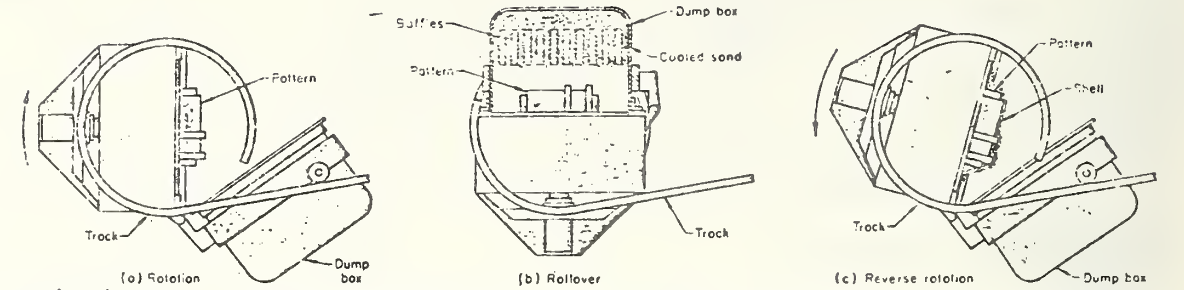
Source: Forging and Casting, Volume 5 of The Metals Handbook

FIGURE 1
Dump Box Method of Making a Shell Mold

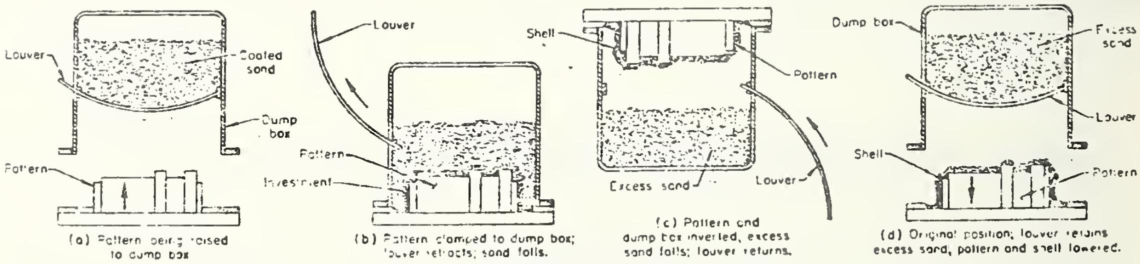
When the desired shell thickness is obtained, the pattern is inverted, allowing the excess resin-sand mixture to drop back into the container. While still on the heated pattern, the investment (now called the shell) is finished by curing in an oven. It is extremely important to maintain the proper temperature relationship between the pattern and the curing oven, to prevent warpage or distortion of the shell mold. After the curing cycle, the shell is ejected from the pattern. In the final operation, any cores to be used are set, and the shell halves are bound together with glue. The mold is then ready for pouring.

For casting, a number of molds may be arranged in stacks or installed side by side in a box, the voids between the molds being packed with steel balls to hold them firmly in position. When the casting metal solidifies, the resin bond in the shell eventually is destroyed by the heat released from the metal so that the sand can afterwards be easily shaken off the solidified casting.

The dump box used may have certain variations as shown in Figure 2.



Variation A: Dump-box method in which pattern and dump box are rotated at high speed on a circular track



Variation B: Shell mold made by using a louver type dump box

Source: Forging and Casting, Volume 5 of The Metals Handbook

FIGURE 2
Dump Box Variations

Blown-Shell Technique

In blown-shell molding, the molding sand is introduced into the molding box by a blowing device and is completed to form a shell-like mold around the heated pattern. The remaining steps are the same as those used in the dump box process.

The blowing machines must be water cooled to prevent the sand from curing while in the blow machine chamber. In addition, there are many shortcomings to the blown shell technique, as follows:

- Pattern and pattern maintenance costs are high.

- Vents clog easily, resulting in a high scrap rate.

- Additives can separate out eacily while the sand mixture is blown into the molding box.

Despite these shortcomings, this technique is still widely used in the auto industry.

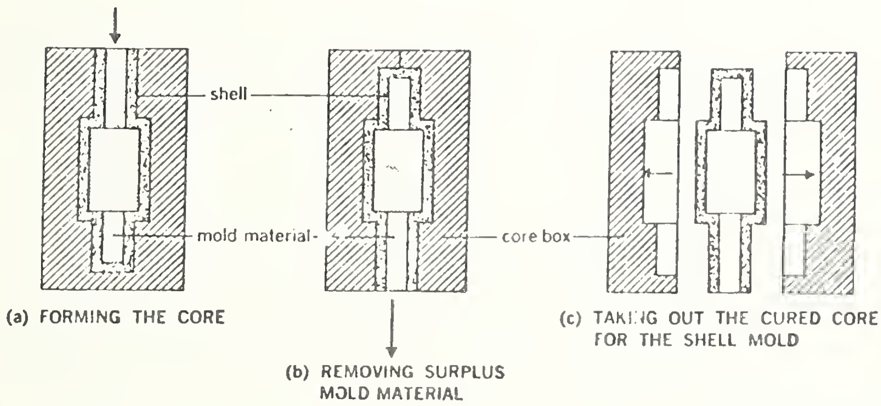
4.2.3 Coremaking Techniques

Cores can be made for shell mold casting in the same manner as cores used for green sand molding. Three methods of particular interest are:

- Shell core making
- Hot box core making
- Isocure process.

Shell Core Making

The shell core process is very similar to shell molding. A metal core box, usually of gray iron, contains the outline of the core (see Figure 3). The box is heated to about 500°F and sand is added to the box. Sand next to the box sets into a shell and the rest of the sand is removed.



Source: Forging and Casting, Volume 5 of The Metals Handbook

FIGURE 3
Forming the Shell Core

The shell core is hollow and light and therefore less expensive to handle than solid cores. In addition, the shell core is smooth and precise, matching the dimensional accuracy and finish of a shell mold. However, a shell core can break and cause iron pieces to solidify inside the core. As a result, modern automotive shell foundries tend to rely more heavily on hot box core methods which are derivatives of the shell core procedure.

Hot Box Core Making

The hot box process produces cores that are solid rather than hollow. Otherwise, it is basically the same as the shell core process just described. The sand for the core is mixed with a compound that produces gases when contacted with the hot core box. The gases solidify the core. This is the predominant process in the auto industry.

Isocure Process

This process does not require a heated core box. A sand-resin mixture is blown into a vented core box. An amine gas is blown through the core, contacts the resin and produces an instantaneous cure to harden the core.

4.2.4 Metals Used

Shell mold casting can be used for most ferrous and nonferrous metals. Shell mold cast automotive parts are generally gray or ductile iron.

Gray Iron

Gray iron is the most commonly used material for shell mold casting of auto parts and components because of its wear resistance, ease of casting, lubricating properties, good vibration damping characteristics, low expense, and high thermal conductivity.

Ductile Iron

Ductile iron is a recently developed type of cast iron. The molten iron is treated with an alloy (usually magnesium and cerium). Careful metallurgical control results in an iron with greater strength and ductility than gray iron. Ductile iron castings are more expensive than gray iron castings. Ductile iron also has poorer heat transfer capabilities than gray iron.

4.3 ADVANTAGES AND DISADVANTAGES OF SHELL MOLD CASTING

Shell mold casting can be used for making production quantities of castings that range in weight from a few ounces to approximately 400 pounds, in virtually any metal. The shell mold casting process has the following major advantages:

- Greater dimensional accuracy attainable with shell mold casting (as compared with conventional green sand molding) can reduce the amount of machining required for completion of the part.
- Much smoother surfaces can be obtained than with green sand molding.
- Less sand is required than in green sand molding.
- There are fewer restrictions on casting design.

The disadvantages of shell molding are:

- Shell mold patterns must be machined from metal and therefore are very expensive.
- The resin binders used in the shell mold process are expensive.
- Sand is not readily recyclable.
- Gates and risers must be incorporated into the shell mold pattern and are more expensive to remove than in sand casting.
- Shrinkage factors vary more with shell molding than with other casting practices and are usually unpredictable.
- More equipment and control facilities are needed, such as for heating the metal patterns.

The problems most frequently encountered in shell mold casting include:

- Mold Cracking. Mold cracking results from thermal stress that develops when hot metal is poured into the cold molds. If the crack extends into a casting cavity, it can cause bleaching and metal runouts, dimensional inaccuracy and distortion of castings.

This can be prevented or controlled by using special sands with less thermal expansion, using thermoplastic additive and by directing the crack.

- Soft Molds. Soft cores can result from a low resin content or excessive additions of vinsol, iron oxide, and silica flows. A pattern temperature that is too low will produce undercured, rubbery shells and cores. Softening of molds can occur during pouring. Usually, this is caused by pouring at too high a temperature or by inadequate mold venting. Mold softness results in inaccuracy of casting dimensions and rough surfaces.

- Low Hot Tensile Strength of Molds. Low hot tensile strength is caused by low curing, resulting in broken shells at the molding machine. However, tensile failures may result from the combined action of resin content, type of resin, catalyst content, and solvent retention.

4.4 AUTOMOTIVE APPLICATIONS OF SHELL MOLD CASTING

The major automotive applications of shell mold casting are cams and crankshafts, and these in general are made by captive shops within the automotive industry. Crankshafts are made out of ductile iron and camshafts are made from a special alloyed gray iron. Other shell mold cast automotive parts include exhaust valves, transmission parts, hubs, and carriers. (See Figure 4.) Figure 5 shows a lightweight crankshaft from Ford made by shell molding and the shell mold used to make the crankshaft.

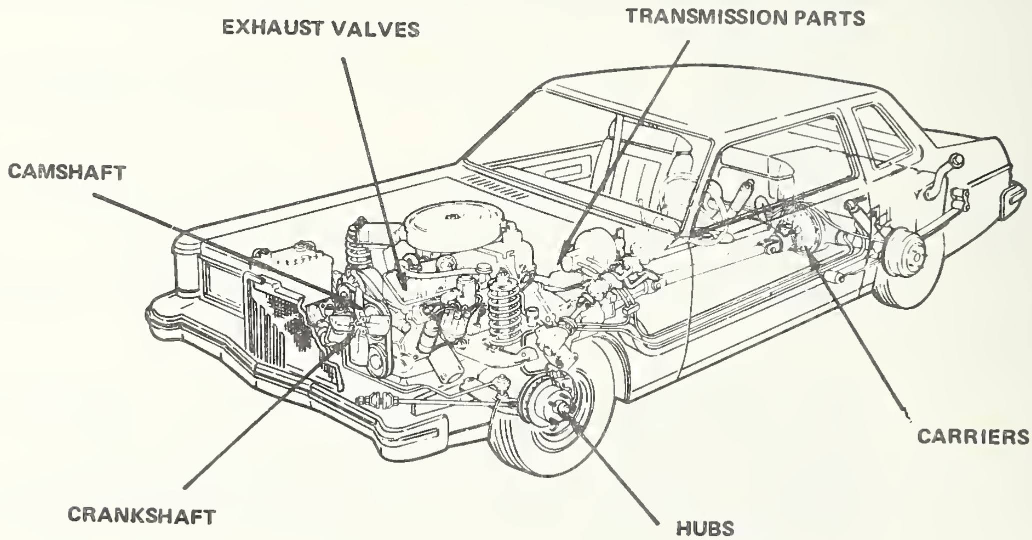
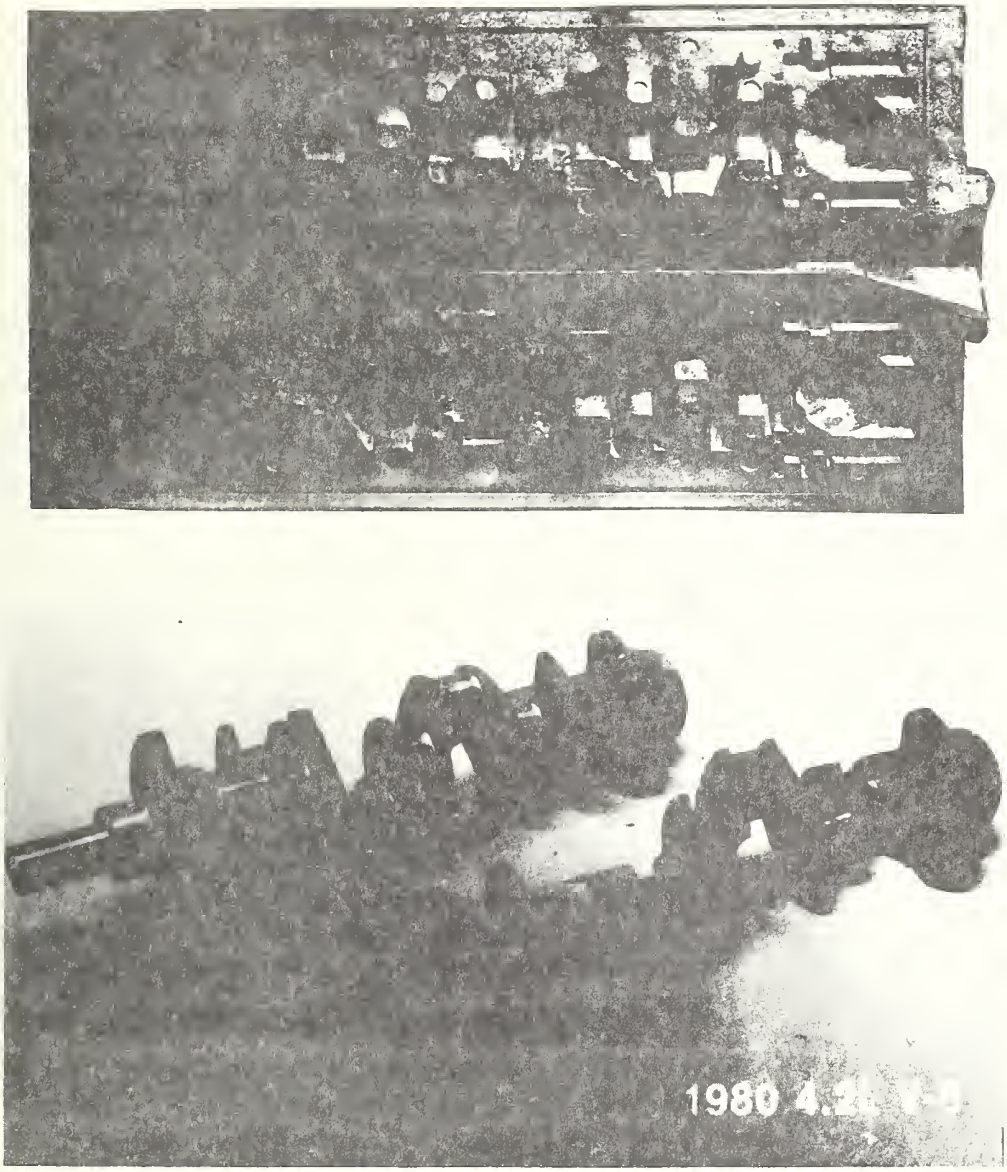


FIGURE 4
Shell Mold Cast Automobile Components



Source: Ford Motor Company

FIGURE 5
Ford Crankshaft and Its Shell Mold

4.5 EQUIPMENT REQUIRED

The equipment requirements to accomplish shell molding are numerous and, except for the actual molding equipment and the sand handling and shakeout equipment, they are identical to that of a sand casting foundry. Core machines, and melting and other equipment are also discussed below.

4.5.1 Shell Molding Equipment

Automatic molding equipment today both slings or blows resin-impregnated sand and cures it in a pattern box. Modern and versatile equipment such as that manufactured by the Redford Division of I.M.C. Corporation can be very easily changed over from shell molding to hot box core making.

Unlike automatic green sand molding machines which rapidly process hundreds of flasks per hour, shell molding machines are much slower, with cycle times of one to two minutes. This is because time has to be allowed to cure the shell sand. Thus shell molding is often done with many molding lines instead of the few lines characteristic in large green sand foundries.

Shell molding machines are generally less expensive than green sand molding machines. The molds are lighter and the molding machine must process less sand. However, the multiplicity of machines needed to do large production work means that mold handling equipment, conveyors, and other support equipment are a significant expense in the shell mold operation. (See Table 1.) In addition, shell mold pattern investment is substantially higher than an equivalent green sand mold pattern investment. Metal shell mold patterns may cost as much as $25,000 versus $7,000 for a green sand mold pattern, and many more are needed since more molding lines are used. Nevertheless, shell molding equipment is still somewhat less expensive than green sand mold machinery. However, in the context of the expense for an entire foundry the difference is not so great that the greater operating expenses of shell molding (the resins and sand costs) are offset.

The heating elements in shell molding machines can be either gas or electric, although most foundrymen have preferred the gas type.

Shell mold machinery is manufactured by Sutter and I.M.C. Corporation. A shell molding machine which can process 60 molds per hour costs about $130,000.

TABLE 1

Foundry Equipment for Shell Mold Casting*

Equipment	Manufacturers	Capacity	Cycle Time	Lead Time	Price
Shell mold double mold blowers	Sutter, and I.M.C.	32"x32"	60/hr		$130,000
Shakeout table	Simplicity, Beardsley & Piper, and Jeffrey	6'x8'		6 months	80,000
Sand transport system	Sand Mold Corp., Einich, and Macawber	10-30 ton/hr			600,000-1,000,000
Muller	Beardsley & Piper, and National	10 ton/hr 5 ton/hr 10 ton/hr		6 months	190,000 78,000 120,000
Core machines (Isocure)	Osborn, Herman and Sutter	30"x40" 23"x27"	1,000 cores/hr (4" diam., 9" long)		100,000 30,000
Tumbleblast	Wheelabrator-Frye	75 ft^3/hr 225 ft^3/hr			130,000 370,000

* Melting equipment is detailed in the Sand Casting chapter of this report.

4.5.2 Sand Handling Equipment

The key parts of the sand handling equipment are the shakeout table, sand transport system, and mulling machines.

Shakeout Table

Because shell mold castings are relatively small and are cast by this method to obtain a superior surface finish at close dimensional tolerance they are not subjected to the abuse imposed by flask (sand molding) shakeout. A gently oscillating conveyor is sufficient to perform the task.

Shakeout tables are manufactured by Simplicity Molding, Beardsley and Piper, and Jeffrey Manufacturing. A typical 6 ft x 8 ft machine capable of handling about four molds per minute costs about $80,000. (See Table 1.)

Sand Transport Recycling Systems

Sand recycling in the shell foundry is different than in a green sand foundry because of the need to blast apart tightly bound chunks of cured sand and remove the resin. The difficulty of recycling shell sand and the lower volume of material compared to green sand molding has led many foundries to bypass shell sand recycling and use new sand every day. However, the rising cost of sand and the difficulty in recent years of finding locations to dump old sand has made this type of operation quite costly.

Sand transport systems for recycling sand vary considerably in design and complexity and are custom made to the individual foundry requirements. The cost varies considerably depending upon options, usually between $600,000 and $1,000,000 for a medium sized shell foundry. A machine capable of recycling 15 tons of sand per hour, for example, would cost approximately $750,000.

Prominent manufacturers are Einich Corporation of Canada, Sand Mold Corp., and Macawber Engineering, Inc. These general contractors will subcontract the ordering of mixers (mullers for sand casting), conveyor belts and pneumatic transport systems they do not manufacture themselves.

Mulling Machines

Mulling machines mix sand and its constituent components with resin into a uniform slurry for subsequent use in molding machines. The leading manufacturers of mulling machines are Beardsley and Piper Division of Pettibone Corporation, Simpson Corp., Clearfield and National Corp. The machines function through a stirring action or the mixing action of rotating wheels. They are rated in tons per hour and horsepower. National's mixing machines for the shell mold industry are rated at 10 and 20 horsepower, 5 and 10 tons per hour and are priced at $78,000 and $120,000 respectively.

4.5.3 Core Machines

Shell cores have not proved very popular even in shell casting because the cores can cave in and cause defective castings. Instead, the shell mold industry has often used the hot box method (which results in solid cores) for coremaking. In addition, more advanced cold box methods of making cores, such as the Isocure (amine) process, have become popular because of low energy consumption and fast cycle time. The cycle time can be as low as 15 seconds for core curing that would take minutes with the hot box process. However, the process has the added cost of machinery needed to separate the amine gas from operators and scrub it before exhaust. Even with the $4,000-$5,000 incremental capitalization cost for this process, the increases in productivity and lowered energy cost clearly outweigh the extra initial cost. In total the new Isocure amine gas systems cost about $30,000 depending upon control feature options.

4.5.4 Melting Equipment

The melting area of a foundry is largely independent of the molding technique employed. Its technology is a function of the metals employed and the tons per day required at the spout. The major categories of equipment for melting are cupolas, induction furnaces, and electric arc furnaces, as in sand molding. The cost of a cupola with the capability to melt 40 tons per hour is around $2 million with another $2 million needed for installation.

4.5.5 Other Equipment

Other equipment similar to that found in a sand foundry includes:

- Cleaning equipment
- Pouring equipment
- Conveyors
- Laboratory equipment
- Heat treating equipment.

Manufacturers of this equipment include Beardsley and Piper, Jarvis E. Webb, and Sunbeam. The cost of the equipment varies according to the size of the casting, the layout of the foundry and the type of metal being used.

4.6 SIZE AND STRUCTURE OF THE SHELL MOLD CASTING INDUSTRY

Shell molding is a specialty molding segment of the casting industry, and can be used for both ferrous and nonferrous metals. While shell molding lines are distinct from green sand molding facilities, companies that do shell molding often also do sand casting. In addition, shell molding foundries serve the same markets and make the same parts as green sand foundries. Companies that do shell molding include Lynchburg Foundry, CWC-Textron, Eaton, and Grede.

Lynchburg Foundry, in Lynchburg, Virginia, did much pioneering work in shell molding in the 1950's, and is the leading producer of castings by this method. Lynchburg continues to be a major supplier of shell molded iron parts to the auto industry. Shell molding is rarely used in automobiles; shell molded parts account for an estimated 8 percent of cast iron parts. Most of the major auto companies have captive shell mold foundries. Captive shell mold castings include crankshafts and camshafts. Shell casting in the auto industry is presently declining according to sources familiar with the automotive foundries.

4.7 TYPICAL PLANT

The typical plant considered for shell molding will be a high production plant pouring 30 tons per hour of iron. This size is nearly the same as the typical green sand molding plant, so the two can be compared.

4.7.1 Plant Layout

A typical shell molding plant is similar to a sand casting plant with key differences in the molding area.

Brief descriptions of each of the major areas in the plant are given below. Figure 6 shows a typical plant layout. The square feet devoted to each area of the plant is shown in Table 2.

TABLE 2
Estimates of Floor Space Requirements
for Shell Mold Foundry

Manufacturing Process	Thousands of Square Feet
Materials Receiving	30
Melting	42
Sand Mixing and Reclamation	27.5
Shell Making	14
Shell Assembly and Storage	11
Mold Line Including Pouring	18
Shot Handling	3
Shakeout	6
Break-off	2.5
Heat Treat	17
Cleaning	17
Inspection	8
Shipping	10
Administrative and Misc.	32
TOTAL	238

Source: H. Bogart, Industry Consultant

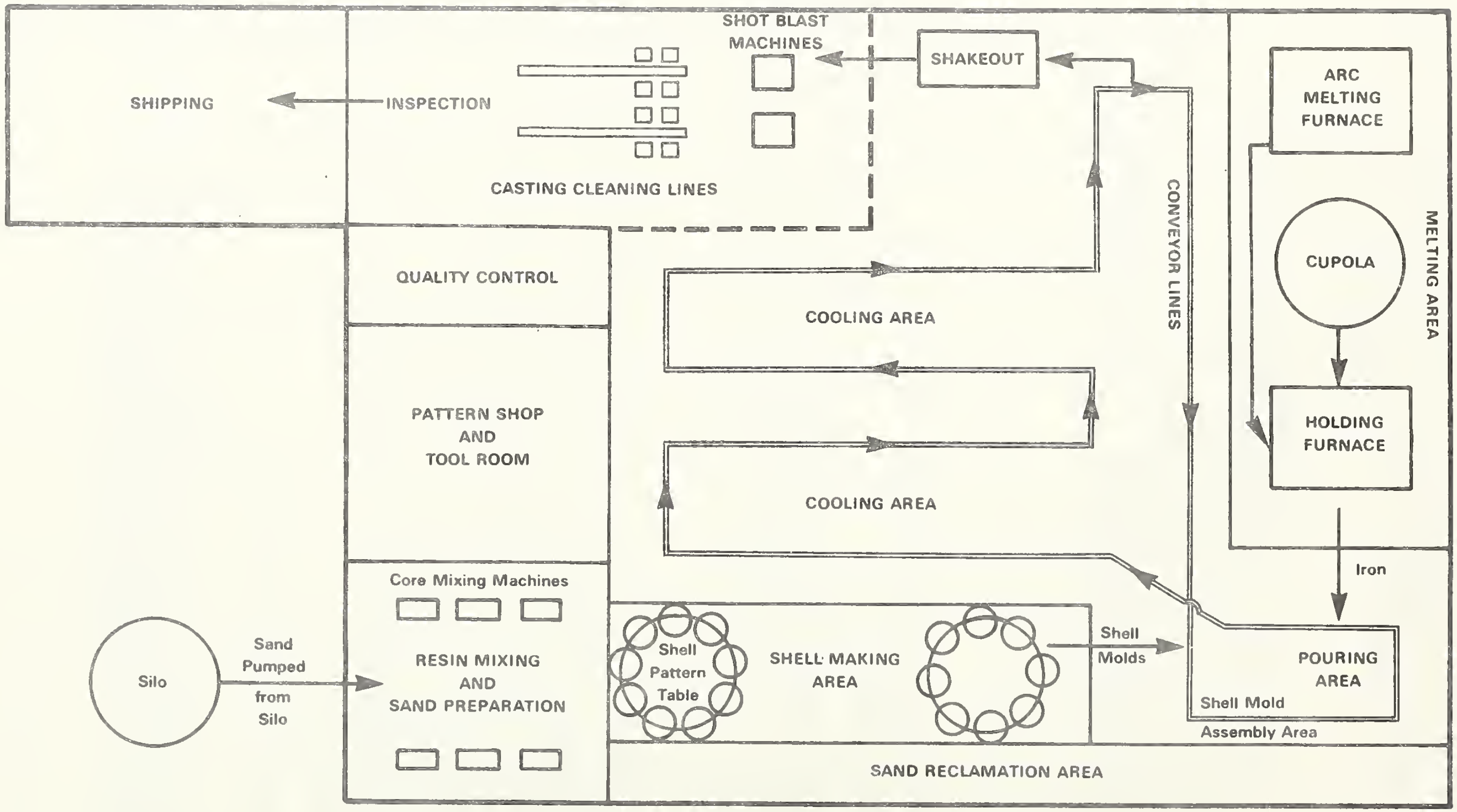


FIGURE 6
Typical Shell Mold Casting Plant

The Melting and Pouring Area

The melting area in a shell molding foundry is similar to that in a sand foundry but usually on a smaller scale. This is because the parts cast such as cam and crankshafts are much smaller than engine blocks. In the melting area is found equipment such as cupolas, arc melting furnaces, holding furnaces, ladles and transfer devices for hot metal. The loading of the cupola with scrap iron and coal or the charging of the arc melting furnaces with ingot is the responsibility of the melting department.

The pouring of hot metal is accomplished by means of a ladle. The transfer into the ladle can be done by means of a minirail* system, but in the small shops one can still expect to find molten metal being transferred by means of portable ladles on fork lift trucks. The actual pouring ladles are controlled by sophisticated machinery which can tilt them at rapid intervals.

Pattern Shop and Tool Room

The pattern shop is where patterns are made. The techniques vary depending upon the anticipated production runs of the part and metals involved. The tool room is adjacent or located within the pattern shop. Its responsibilities are the same as that described under sand casting.

Core Room

In the core room resin mixing and sand preparation are performed independently; then in mulling machines they are blended before being blown into the hot box cavities of coremaking machines. Assembly operations take place in the core room when complex cores must be assembled; this usually takes place on slow moving conveyor belts.

Shell Making Area

The shell making area is the heart of the shell foundry. Incoming resin-impregnated sand is blown onto hot patterns of 450°F temperature where it is cured in a few minutes on

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* A minirail is an overhead monorail system.

a circular rotating table. The shells are then taken off the patterns and transferred to the molding line for mating to a lower half. The shell making function is relatively simple compared to the analogous functions in a sand foundry.

Shell Molding Lines (Assembly)

In contrast to a sand foundry the molding lines in a typical shell molding foundry are often floor level conveyors. These types of conveyors require far less investment than an overhead conveyor. The molding lines must extend for at least 30 minutes to allow the proper cooling of the part.

Shakeout

During shakeout the sand shell is broken from the metal part. In the shakeout area the parts are placed on a large table with a screen top which vibrates vigorously. The sand is transported usually pneumatically to a reclaiming area and then to a muller for mixing and resin impregnation.

Cleaning Room

The first step in the cleaning process is shot cleaning where parts are fed into a machine and are bombarded by BB-sized steel shot. This thoroughly cleans all surfaces. If the part has a core, vacuuming of the interior cavities will take place.

Inspection

When the castings have been thoroughly cleaned, they are inspected by quality control personnel for dimensional accuracy and any defects. The castings are then ready to be transferred to the shipping area for packing and shipping.

4.7.2 Materials Flow

Principal materials which are handled in a shell casting foundry include iron scrap, resin materials, and sand. The flow of each type of material through the plant layout illustrated in Figure 6 is discussed below.

Iron

Scrap is brought in from outside the foundry, melted in the furnaces, and held in the holding furnace. The metal is transferred in ladles to the pouring area. The poured metal becomes the castings. Forty to fifty percent of this poured metal is used for risers, gates, and parts that are unacceptable. This metal is recovered after casting shake-out and is returned to the melting area for remelting.

Resin

Resin is needed to coat all the sand used in the shell molds. This is done at the resin mixing and sand preparation area. The resin travels with the shell mold and either leaves the foundry with discarded shell sand or is removed from the sand and disposed of if the sand is recycled. The resin is not recoverable.

Sand

Sand is pumped into the sand preparation area from outside the foundry, mixed with resin, and transferred to the shell making area. The shells are broken up at shakeout. If the foundry reclaims its sand, the sand is shipped to the reclamation area. Here the organic remnants of the resins are removed and the sand is regranulated. The sand then is transported to sand preparation where it is mixed with new sand and resins.

Typical Materials Requirements

A shell plant pouring 480 tons per day of iron will yield about 300 tons of good castings. The rest of the metal will be remelted.

Sand use varies depending on part size. Pouring 30 tons per hour will generally require 10 to 30 tons of shell sand per hour. Assuming the lower figure, daily sand usage will be about 175 tons. If reclaiming is done, new sand requirements would be about 10 percent of this. If the sand is not reclaimed the entire tonnage would have to be purchased each day. Shell sand requirements are under 10 percent of green sand molding sand requirements.

Resin use is generally about 2 to 5 percent of sand use by weight. Thus the 30 tons per hour shell molding plant would use the following quantities of materials:

- Metals - 300 tons per day
- Sand
  - New - 15 tons per day
  - Reclaimed - 160 tons per day
- Resin - 10 tons per day.

4.7.3 Capital Requirements

The capital requirements developed in this section reflect a large automotive shell mold foundry pouring 30 tons of iron per hour. Total capital investment requirements are estimated at $23 million for land and a building, and $26.7 million for equipment.

Land and Building Requirements

The plant size and land area are estimated to be nearly equivalent to the sand casting facility. Total costs are shown in Table 3.

TABLE 3
Land and Building Requirements
For a Shell Mold Foundry

Capital Requirement	Cost
Land	$ 3,000,000
Building	20,000,000
TOTAL	$23,000,000

Equipment Requirements

Table 4 lists the equipment requirements and their cost for a shell mold foundry pouring 30 tons of metal per hour. Although there are some variations in the costs of various parts of the plant, the total plant cost is very close to the cost of the green sand foundry described earlier.

The significant capital differences between this plant and the sand casting plant discussed earlier occur in molding equipment, sand handling equipment, and sand preparation equipment.

- Sand Molding Equipment. Eight 60 blow per hour double machines, which together would cost $1.4 million, would be required. In addition, other mold handling equipment (rollover and rollout conveyor and closer) would add another $80,000 for each machine, and a pouring and cooling line would cost about $500,000. Altogether, the shell molding lines would cost about $2.6 million. This compares to about $4 million for the equivalent green sand mold system.

- Sand Handling Equipment. The requirement for shell sand is between 10 and 30 tons per hour depending on the parts being produced. This compares to 300 tons per hour in the green sand foundry. Thus the estimated sand handling equipment cost in the shell mold foundry is about $600,000 compared to $3 million in the sand casting plant. However, many shell foundries employ a back-up shot system to support the shell molds. The transport system for this material could bring the total cost of material transport near that of the green sand mold sand transport cost.

  In addition, a shell foundry that recycles its sand would require an expensive sand recycling system. This system would add an estimated $750,000 to the cost of shell sand transport.

- Sand Preparation Equipment. A resin-sand mixer/muller capable of mixing 10 tons of sand per hour costs about $190,000. If the plant wants the capability of mixing 20 tons of sand per hour, the cost would be $380,000.

TABLE 4
Equipment Requirements for a Typical Shell Mold Foundry

Equipment	$ (Millions)
2 Cupolas, 30 tons/hour, installed	7.8
Pouring system	.5
Holding Furnace	.25
Molding Equipment, installed	3.1
Conveyor	2
Core machines	1.2
Resin mixing	0.2
Other core support	1.1
Muller/Resin mixer	.46
Shot/Sand handling equipment	2.9
Sand reclamation	.75
Wheelabrator	.45
Other cleaning equipment	3.00
Lab	0.7
Heat treat equipment	1.0
Raw materials handling	0.25
Other	1.00
TOTAL	26.7

4.7.4 Labor Requirements

The labor utilized in a shell molding operation is not significantly different than that used in a sand casting facility. Table 5 shows a typical labor breakdown.

TABLE 5
Labor Requirements for a Shell
Foundry Pouring 30 Tons Per Hour

Skill	Number
Administrative and Skilled, including:	100
• Plant manager	
• Department managers, quality control, production, accounting, manufacturing engineering, industrial engineering	
• One metallurgist and staff of 20 specialists	
• Sand and resin technologists	
• Pattern makers	
• Tool and die makers	
• Melting technologists	
• 20 foremen	
Unskilled, including:	
• Shift 1 production workers	300
• Shift 2 production workers	300
TOTAL	700

4.7.5 Energy Requirements

Since energy requirements in a foundry are determined basically by the melt energy requirements, the energy requirements in a shell foundry would not be significantly different from the energy requirements in a sand foundry. This is about 700 kw per ton of metal, plus 150 kw per ton for holding metal. A shell mold foundry would require some extra energy in order to heat the patterns if a hot box process is employed. In addition, heating costs would be extra and dependent on the geographical location of the plant.

4.8 KEY ISSUES

Traditional shell mold casting employing phenolic resins never gained wide popularity. Its use was limited to parts requiring good surface finish and dimensional accuracy such as cam and crankshafts, to minimize machining costs. The basic reason for its lack of acceptance in the industry was the large amount of expensive resins and catalysts used in each cycle of the sand system. Also important was the necessity of removing organic remnants of the phenolic resins after shakeout and regranulating the sand by blasting it against a surface. All of these problems proved costly.

Recently improvements in resin technology have allowed high cycle rates and excellent quality to be obtained by the use of gas cured resins. The CO , SO and amine gases (Isocure process) all helped to increase productivity in both the shell molding area and the coremaking area. The most recent advances have been made with amine gases, even though they require additional hooding and exhaust scrubbing devices. The fact that the amine gas (Isocure) process is done cold saves greatly on the energy consumption of the foundry, and this gives hope for the future use of amine gas techniques in shell mold casting, especially in the coremaking area.

The question of the toxicity of amine gas is the only potential problem of the new cold box systems. The industry contends that it is nontoxic while unions involved are skeptical.

5. PERMANENT MOLD CASTING

5.1 GENERAL

Permanent mold casting consists of filling a mold with metal as in sand casting, except that the mold itself is solid metal. No pressure is used other than gravity to force the metal into the mold; therefore pouring techniques are especially important for preparation of good castings. The process is used successfully for both ferrous and non-ferrous casting, although it is best applied to lower melting point alloys such as aluminum. The simplest type of permanent mold hinges at one end of the mold with provision for clamping the halves together at the other. Highly automated permanent mold casting machines are circular in arrangement and have molds placed at a number of stations around a turntable.

The most widespread automotive applications of permanent mold casting are in light to medium weight aluminum components such as master cylinders and intake manifolds. The near-term outlook is good for increased use of aluminum permanent mold casting, while gray iron applications are expected to continue at the current level or decline. The process results in a casting with good surface finish free from burnt-in sand, but is relatively expensive due to the high cost of molds and hydraulic equipment to open and close them.

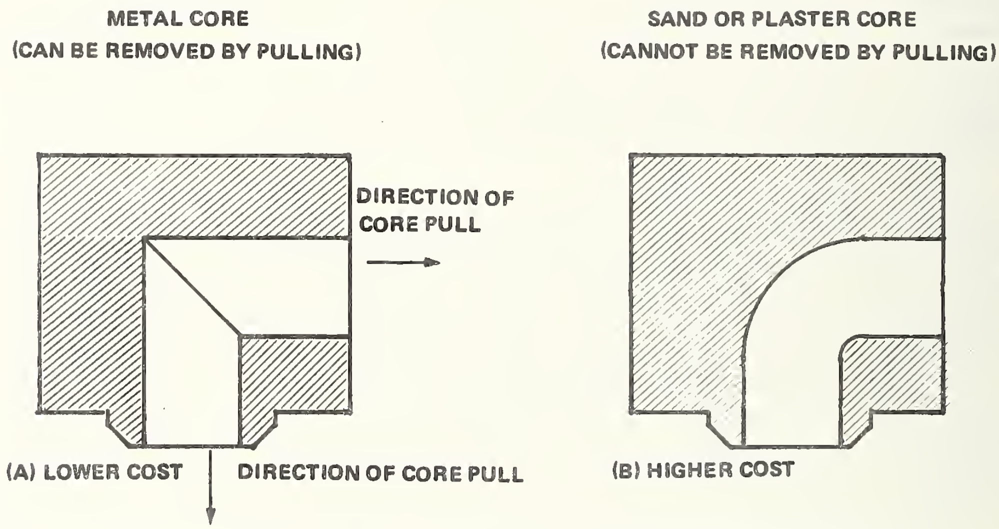
5.2 TYPES OF PERMANENT MOLD CASTING

Permanent mold casting is distinguished from other casting by the use of a long lasting metal mold and the absence of force, other than gravity, in filling the mold.* Metal, dry sand or plaster cores can be used. When a sand or plaster core is used the process is called semi-permanent mold casting. With sand or plaster cores, which are expendable, more complex shapes can be produced than with metal cores.

* Low pressure casting, where seven to eight pounds of pressure is applied to the flowing metal, is closely related to the permanent mold casting technique. This process is not widely used in the automotive industry.

5.2.1 Core Material

Cores may be metal, sand or plaster. For simple casting designs, a metal core is inserted into the mold just before pouring, and extracted when the casting begins to solidify. Other metal cores are designed as firm fixtures attached to the mold. If the core area is complex, a sand or plaster core may be used, as in the air intake passages of a manifold. Figure 1 illustrates two cases where metal and expendable (sand or plaster) cores are used. Types of cores frequently used include collapsible, sand and plaster cores.



Source: Forging and Casting, Volume 5 of The Metals Handbook

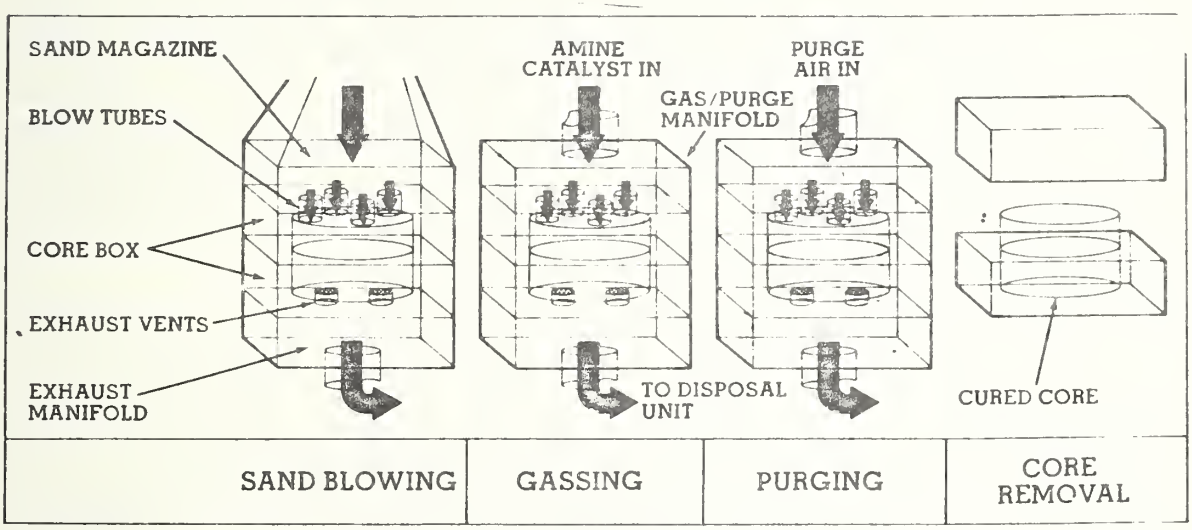
FIGURE 1
Different Core Material Applications

Collapsible Cores

Collapsible cores are multi-piece metal cores which must be assembled into each mold for pouring. A five-piece collapsible core has been used extensively in the manufacture of aluminum pistons despite a number of technical problems inherent in the use of such cores. Dimensional variations can result from the use of collapsible cores because they cannot be positioned as securely in the mold as single piece cores. Also, assembly and removal adds substantially to production time. Cores are removed as soon as the casting has solidified to prevent adhesion to the mold.

Sand Cores

Sand cores are used extensively for the manufacture of intake manifolds. A principal technique for preparing sand cores is the Isocure process. This process involves passing a catalytic gas through the sand-resin mixture in the core box. The gas enters the core box through blowholes or vents and passes through the core, causing almost instantaneous hardening of the resin coated sand. This process is illustrated in Figure 2.



Source: Ashland Chemical Company

FIGURE 2
Diagram of Isocure Process

Sand cores are knocked or blasted out of the casting after solidification take place. In cases of exceptionally intricate coring, a specially designed air hammer or shot blast machine may be required to remove the residual sand.

Plaster Cores

Plaster cores are used in semi-permanent molds to provide a surface finish better than is obtainable with sand or coated metal cores. In dimensional accuracy, however, plaster cores offer no superiority over sand cores. Plaster cores are not frequently used for the manufacture of automotive components.

Mold Coating

A mold coating is applied to the permanent mold and core surfaces to serve as a barrier between the molten metal and the surfaces of the mold while a skin of solidified metal is formed. Mold coatings are used for several purposes:

- To prevent premature freezing of the molten metal
- To control the rate and direction of solidification of the casting and thus its soundness and structure
- To minimize thermal shock to the mold material
- To prevent soldering of molten metal to the mold.

Types of Mold Coating

Mold coatings are of two general types—insulating and lubricating. Some coatings perform both functions. A good insulating coating can be made from (by weight) one part sodium silicate to two parts colloidal kaolin in sufficient water to permit spraying. Other frequently used coatings are ceramic materials. Lubricating coatings usually include graphite.

Life of Mold Coatings

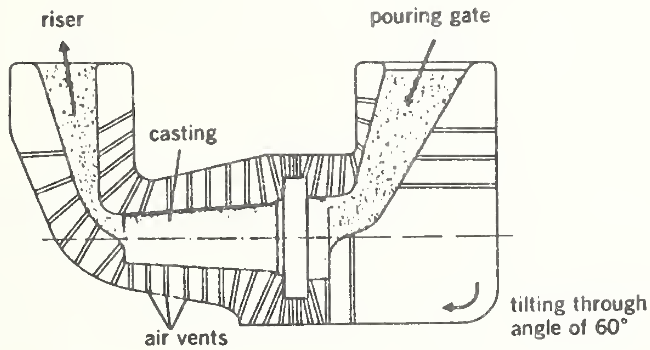
The life of a mold coating varies with the temperature of the metal being cast, the size and complexity of the mold cavity, and the rate of pouring. Some molds require recoating at the beginning of each shift; others may run for several shifts with only spot repairs or touch-ups before recoating is needed. Light abrasive blasting is used to prepare the coating for touch-up, or to remove old coats.

5.2.2 Pouring Methods

A permanent mold must be designed so that the metal can be poured evenly throughout the mold cavity. Unevenness in pouring may result in a poor casting. Factors which are important in pouring are mold design and pouring temperature.

Mold Design

When the metal touches the wall of the mold, a quenching (cooling) action takes place. To prevent the metal from solidifying unevenly therefore, the pouring-gate system and risers must be designed so that the metal will be distributed evenly throughout the mold. In addition, the mold must have air vent holes to enable the air displaced by the casting metal to escape from the interior of the mold. In sand casting, this air escapes through the porous mold material. The permanent mold must also be designed so that the molten metal will flow quickly, without turbulence, into all parts of the cavity. Slowly tilting the mold during casting in order to reduce turbulence and help the metal to flow smoothly, is an expedient that is employed particularly for heavy casting. This tilting technique is illustrated in Figure 3.



Source: Forging and Casting, Volume 5 of The Metals Handbook

FIGURE 3
Tilting Permanent Mold Technique

Pouring Temperature

Generally, permanent mold castings are poured within a relatively narrow temperature range. This range is established by the composition of the metal being poured, the size and weight of the casting, mold coating and gating system. If pouring temperature is lower than optimum, the mold cavity will not fill properly and thin sections will solidify too rapidly. Low pouring temperature consequently results in mis-runs, porosity, and poor casting detail.

5.2.3 Metals Used

Metals which can be cast by the permanent mold technique are principally lower melting point alloys of aluminum, copper and magnesium. Gray iron may also be cast in permanent molds if the molds are coated with a heavy layer of lampblack or other heat insulating material. The predominant material used for automotive components is aluminum.

Aluminum

More aluminum alloy castings are made by the permanent mold process than by any other process except die casting. Normal weight for a permanent mold aluminum casting is less than 30 pounds.

Aluminum alloys with a high silicon content are the best suited to permanent mold casting while those with a high magnesium content are the poorest. The principal benefits in selecting this process for casting aluminum auto parts are the close tolerance and fine surface finish possible.

Copper

Although the permanent mold casting process is applicable for a number of copper alloys, it is better suited to aluminum. The advantages of permanent mold casting over sand casting are essentially the same for copper alloys as for aluminum alloys. Likewise, for copper alloys, a major disadvantage of the permanent mold process is the higher tooling cost.

Copper alloys may tend to shrink onto cores and other mold elements and care must be taken in casting extraction. Coper permanent mold castings are seldom used in automotive applications.

Magnesium

Magnesium alloys cannot be cast as easily or as well as aluminum alloys. Magnesium is subject to brittleness at high temperatures and sharp casting detail cannot be obtained. Magnesium permanent mold castings are seldom, if at all used in motor vehicle manufacturing.

Gray Iron

Permanent mold casting of gray iron is used for high volume productions of small castings (usually weighing no more than 30 pounds). Mold life for casting of gray iron is shorter than for aluminum because of the higher metal pouring temperature for gray iron, the additional weight of the casting, and the heating cycles in the casting process. Gray iron permanent mold casting of automotive parts. is very limited.

5.3 ADVANTAGES AND DISADVANTAGES OF PERMANENT MOLD CASTING

Permanent mold casting is most suitable for high-volume production of small, simple castings that have a fairly uniform wall thickness and no undercuts or intricate coring. The primary advantage of permanent mold casting over other casting processes is that a very accurate finish is obtainable with the use of a metal mold. The process carries a cost penalty, however, since the initial cost for the permanent mold and casting equipment is high. Generally, mold cost per casting should be no more than 10 percent of the selling price of the casting. If mold cost exceeds 10 percent, then an alternative casting method should be considered.

5.3.1 Advantages

Advantages of permanent mold casting are:

- Compared with sand casting, permanent mold casting permits the production of more uniform castings with a superior surface finish and freedom from burnt-in sand.
- The high conduction of heat through the metal mold causes a chilling action which may result in castings of finer grain structure and harder tensile strength. Specified values for tensile strength are considerably higher than those for sand castings.*

* Accuracies on the order of 0.0015 inch to 0.003 inch per inch can often be maintained, and a surface finish of 100 microinches to 125 microinches is possible.

- Cored holes in permanent mold castings can usually be held to closer tolerances, in both size and location, than in sand castings. Both moveable cores and stationary cores can be machined to close dimensions and can be accurately located.

5.3.2 Disadvantages

Disadvantages of permanent mold casting are:

- The cost of the mold and the permanent mold casting machine are high. Generally, production quantities must be high enough to justify the cost of the molds.

- The permanent mold process is not practical for large castings due to the need for high volumes to make the process cost effective.

- Not all alloys are suited to permanent mold casting.

- Some shapes cannot be made by the process because of the location of the parting line or difficulty in removing the casting from the mold.

- Locations of gating systems for permanent molds are less flexible than for sand molds.

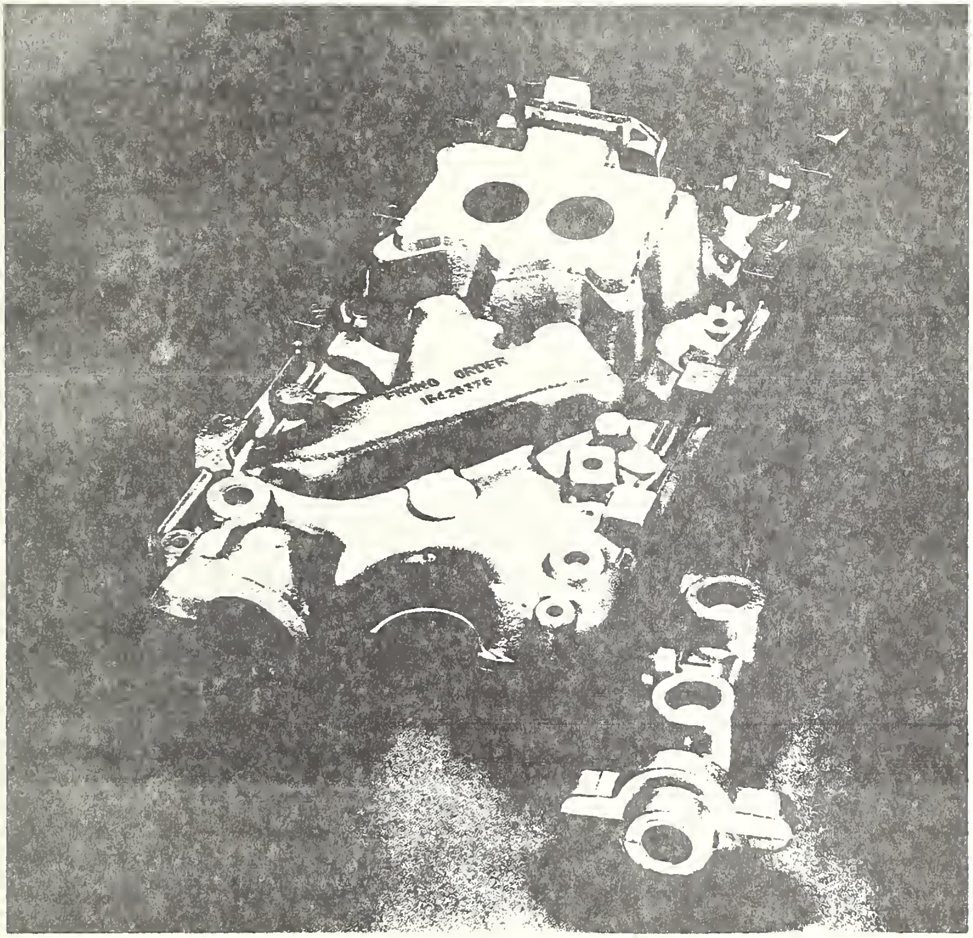
- Metal cores must be shaped so that they can be withdrawn from the finished piece. When sand cores are used, the finish of the cored recesses is often no better than that of sand casting.

5.4 AUTOMOTIVE APPLICATIONS OF PERMANENT MOLD CASTING

Permanent mold casting has not been used extensively in the auto industry. Application of the process for making lightweight aluminum components, however, has increased considerably in recent years.

Because tooling costs for permanent mold casting are higher than for sand casting, the permanent mold process is most often restricted to use for intermediate to high production items. The most widespread automotive application of permanent mold casting has been in the manufacture of aluminum pistons, a high volume item requiring close tolerances. Selected automotive applications of permanent mold casting are shown in Figure 4.

Intake Manifold



Master Cylinder

Source: Hayes Albion Corporation

FIGURE 4
Automotive Parts Made by Permanent Mold Casting

Principal aluminum applications of permanent mold casting include:

- Intake manifolds
- Pistons
- Master cylinder housings
- Cylinder heads.

Their location on an automobile is shown in Figure 5.

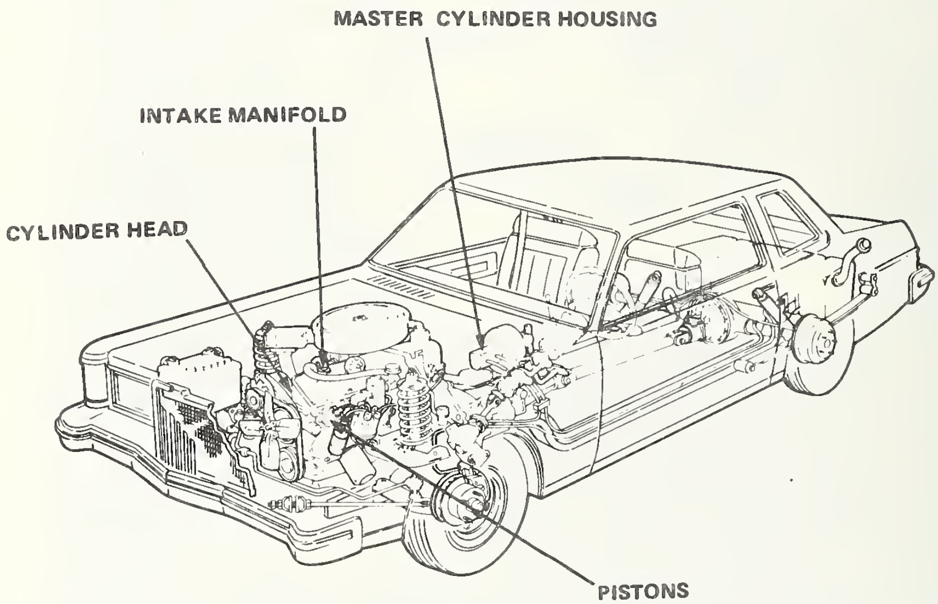


FIGURE 5
Automotive Applications of
Aluminum Permanent Mold Casting

The location of gray iron applications of permanent mold casting on an automobile is shown in Figure 6. The parts include:

- Wheel cylinders
- Proportioning valves
- Fan hub castings for engine cooling fans
- Air conditioning compressor bodies.

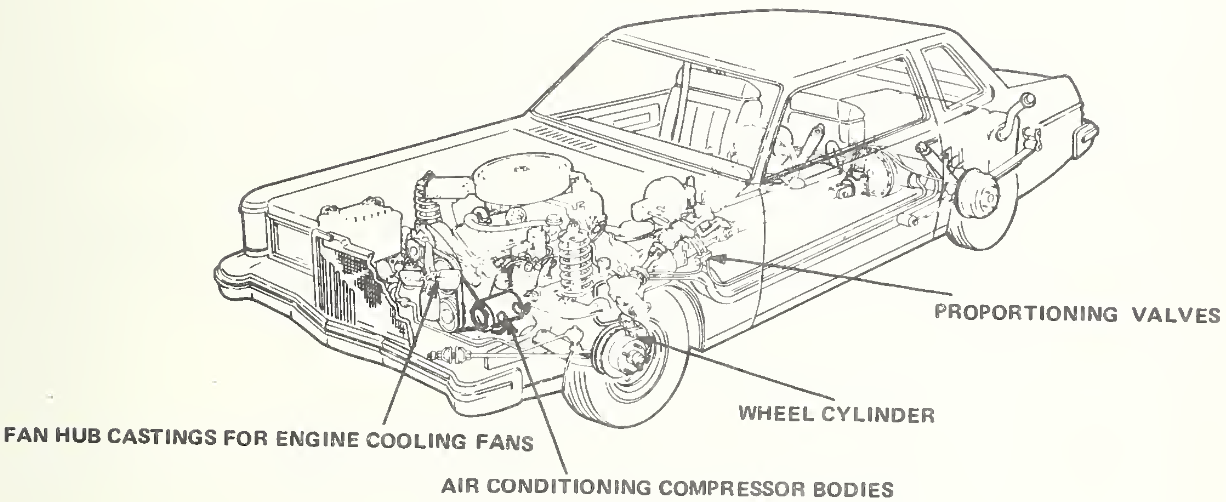


FIGURE 6
Automotive Applications of
Gray Iron Permanent Mold Casting

5.5 EQUIPMENT REQUIRED

Major types of equipment required for permanent mold casting include:

- Coremaking equipment
- Melting and holding equipment
- Permanent mold casting equipment
- Metal cleaning equipment
- Metal inspection and finishing equipment.

5.5.1 Coremaking Equipment

As in other casting processes, coremaking equipment varies according to the type of core being used. Metal cores may be cast out of steel or iron and are often purchased from an independent supplier. When a sand core is used, a sand mixer and coremaking machine are required, with optional equipment including a heater/cooler for the sand and a gas scrubber, depending on the requirements of the coremaking process. Accessories include sand hoppers, core racks and an air compressor. Sample price and capacity data on coremaking equipment is summarized in Table 1.

Sand Mixers

A sand mixer is used to blend the raw sand with various binders or resins to form a compound which will then be hardened into a solid core. Core mixers are available which feed into a single coremaking machine or into three or four machines simultaneously. The price of core mixers ranges from $20,000 for a single feed mixer to $35,000 for a multiple feed or bulk unit. Manufacturers of sand mixers are Beardsley and Piper and C-E Cast Equipment.

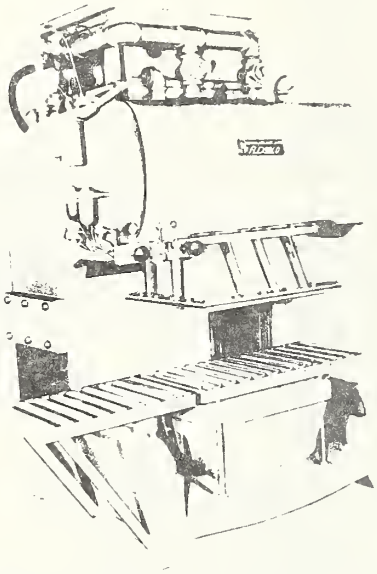
Coremaking Machines

The coremaking machine takes the sand-chemical mixture and forms it into the shape of the core. Usually a core blowing machine is used, which rapidly forces sand into the

TABLE 1
Selected Coremaking Equipment

Equipment	Manufacturers	Capacity	Cycle Time	Lead Time	Price
Sand Mixer	Beardsley and Piper C-E Cast Equipment				$20,000
CB-18CC Flexiblo Core Molding Machine	Beardsley and Piper Gladwin Corporation Sutter Products Co.	125 pounds			$100,000
Continu-Blomatic Cold Box Core/ Mold Machine	Beardsley and Piper	1,200 blow cycle per hour			$74,000
Gas Scrubber	American Envirodyne American Air Filter Company	200 cubic feet per minute			$50,000

core box under air pressure (See Figure 7.) Then, the Isocure process may be used to harden the core. Since the gas used in the Isocure process is toxic, the system through which it passes is completely sealed, and from the empty chamber beneath the core boxes the gas passes into a scrubber. Coremaking machines range in price from $60,000 to $100,000. Manufacturers of coremaking machines include Beardsley and Piper, Gladwin Corp., and Sutter Products Co. Accessories may include an automatic core take-off device (which lifts the core out of the core box) and a no-spill sand hopper which add $10,000 to $12,000 to the equipment price.



Source: Beardslev & Piper

FIGURE 7
Typical Core Blowing Machine

Heater/Cooler

A common requirement for coremaking is that the sand be kept at a fairly even temperature and humidity level before it is mixed with the resins. Depending upon the geographic location of the foundry, equipment may be needed to heat, cool, or heat and cool the sand throughout the year. Raw sand is fed into the heater/cooler by air pressure and then passed over a series of coils. After the sand is sufficiently warmed, it is fed into the core mixer. Heater/coolers are not needed for all coremaking processes. They range in price from $8,000 to $20,000.

Gas Scrubber

A gas scrubber is used to cleanse the coremaking gases of their toxicity before being vented to the atmosphere. The scrubber is a tall tower, often as tall as the roof of the building, which contains a series of fibrous material packs and fluid rinses (See Figure 8). The toxic gases pass through the core box into a chamber below and then into the scrubber. Slight pressure forces the gas up through the scrubber tower where the filters and rinses remove all toxic properties. Scrubbers vary considerably in design and they range in price from $50,000 to $100,000. Gas scrubbers are manufactured by American Envirodyne and American Air Filter Co.

Coremaking Support Equipment

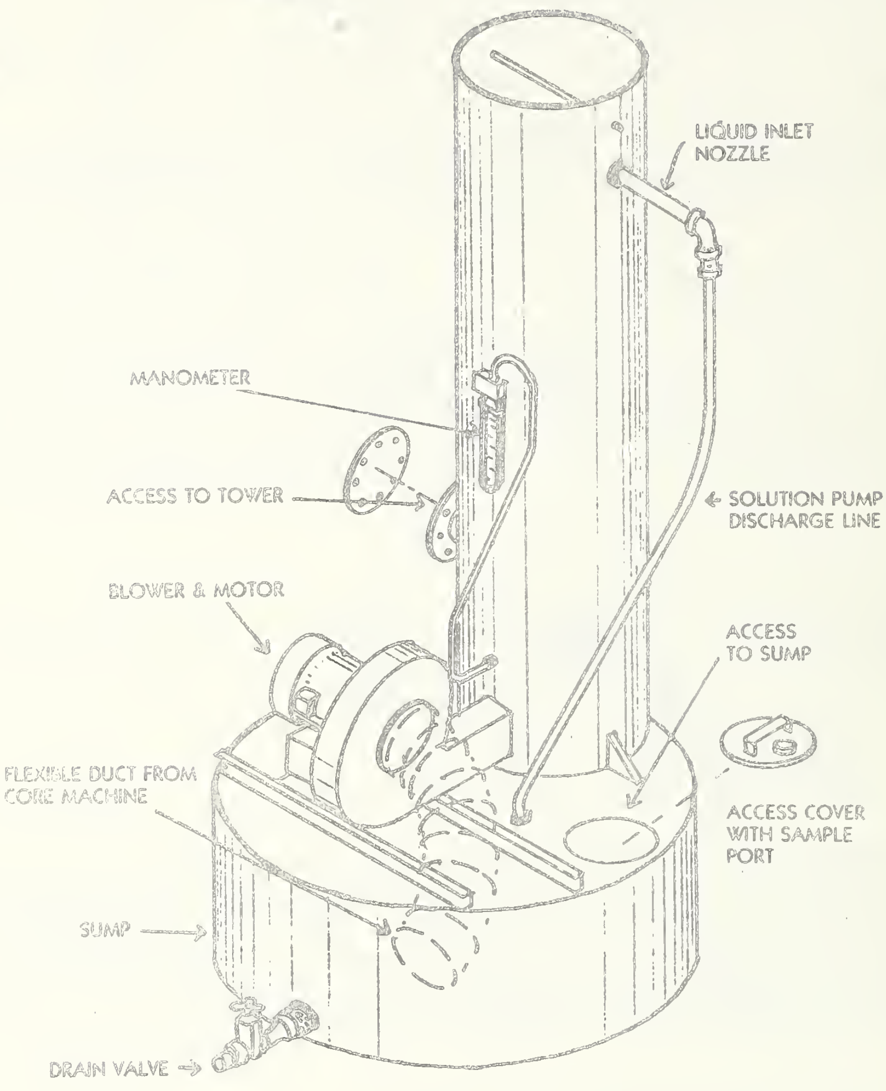
Supporting the coremaking equipment are a range of accessories including:

- Sand hopper
- Core racks
- Air compressor.

The sand hopper feeds sand at a steady rate into the mixing machine. The air compressor provides air pressure for blowing cores into the core box, and the core racks receive and transport the finished cores to the molding area. Sand hoppers cost approximately $3,000 for a 6-ton size, and core racks cost $1,000 each.

5.5.2 Melting and Holding Equipment

Melting and holding equipment includes the melt furnace, holding furnace and ladles for moving the molten metal. Information on the capacity, cycle time, lead time and price of typical equipment is summarized in Table 2.



Source: American Envirodyne

FIGURE 8
Gas Scrubber

TABLE 2
Selected Melting and Holding Equipment

Equipment	Manufacturers	Capacity	Cycle Time	Lead Time	Price
Electric Wet Bath Reverbatory Melt Furnace	Frank W. Schaeffer, Inc.	2,000 lbs. per hour	One hour	4-5 months	$80,000
Electric Wet Bath Reverbatory Hold-ing Furnace	Frank W. Schaeffer, Inc.	3,500 lbs		4-5 months	$30,000
Channel Induction Melt Furnace with Jet Blow Indicator	Ajax Magnethermic Corporation Whiting Corporation Lindberg	5,000 lbs. per hour	One hour	4-6 months	$320,000
Channel Induction Holding Furnace	Ajax Magnethermic Corporation Whiting Corporation Lindberg	5,000 lbs.		4-6 months	$75,000
Automatic Ladle	Lindberg Whiting Corporation				$15,000

Melting Furnaces

Furnaces for melting aluminum alloys include cupola, reverbatory and induction furnaces. In modern permanent mold casting plants electric reverbatory and induction furnaces are the most common. Foundries favor electric furnaces because of the decreasing availability and increasing costs of gas and oil.

Of the two types of reverbatory furnaces (dry-hearth and wet-hearth), wet hearth furnaces are the more widely used. The reverbatory furnace is generally used to melt large amounts of aluminum to supply holding furnaces, or used to remelt scrap metal. Electric induction furnaces are used in the same way. Depending upon capacity and efficiency, aluminum melting furnaces range in price from $30,000 to more than $300,000. Some manufacturers of melting furnaces are Frank W. Schaeffer, Inc., and Ajax Magnethermic Corporation.

Holding Furnaces

A permanent mold foundry may have several small melt furnaces or a central melting unit, either of which will feed into holding furnaces. Holding furnaces have the capacity to heat aluminum which has started to cool, but generally they are used as reservoirs to free the central melt furnace for more production of aluminum. The holding furnaces are equipped with automatic controls that can maintain an established temperature. They are less expensive than the melting furnaces and range in price from $30,000 to more than $75,000. Holding furnaces are manufactured by Ajax Magnethermic Corporation, Whiting Corporation and Lindberg.

Automatic Ladle

Equipment for transferring molten aluminum can range from a small hand ladle to a large truck having an insulated container capable of holding 10 to 15 tons of molten metal. Some furnaces are equipped with tapholes that can be unplugged to allow the metal to flow into a ladle, while others are designed for dipping only. The use of automatic ladles is becoming more common in permanent mold casting since the molding equipment very often involves rotating the mold past a pouring point. When included as a part of a permanent mold casting machine, an automatic ladle ranges in cost from $10,000 to $15,000. By itself, the ladle is priced at approximately $50,000. Whiting Corporation and Lindberg are manufacturers of automatic ladles.

5.5.3 Permanent Mold Casting Equipment

Permanent mold casting equipment includes the permanent mold and the hydraulic machine for opening and closing the mold. This equipment is the focal point of the permanent mold casting process. Prices and lead times on selected permanent mold casting machines are shown in Table 3.

Permanent Mold Casting Equipment

The permanent mold casting machine is a hydraulically powered machine which opens and closes the metal mold in which the molten metal is poured. The opening and closing action, which is timed to a preset cycle, is the essential part of the machine. Machines are available in single station models which control one mold, or multiple station rotary machines with 4 to 12 molds. As shown in Figure 9, the molds are located on a turntable which rotates from the point at which the metal is poured to the point where the mold is opened by hydraulic action. Castings are ejected into casting catchers.

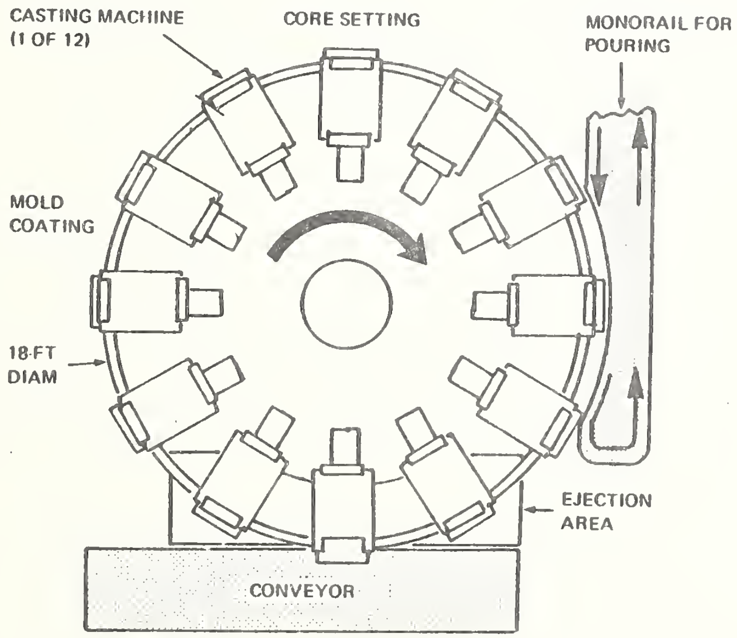


FIGURE 9
Rotary Permanent Mold Casting Machine

TABLE 3

Selected Permanent Mold Casting Equipment

Equipment	Manufacturers	Capacity	Cycle Time	Lead Time	Price
HM Rotary 6 Station Permanent Mold Casting Machine	Hall Level and Manufacturing Works	90 casting per hour	3 minutes	6 months	$119,000
Stahl Rotary 8 Station Automatic Casting Machine	Stahl Specialty Company	160 castings per hour	3.5 minutes	8 months	$235,000
12-Station Rotary Permanent Mold Iron Casting Machine	Eaton Corporation	240 castings per hour	2-7 minutes	6-12 months	According to Bid Specification

Permanent mold casting machines are often manufactured by foundries for their own use. Eaton Corporation and Doehler-Jarvie make their own permanent mold casting machines. Commercially available machines range in price from $50,000 for a single station machine to $300,000 for a multiple station rotary machine. Manufacturers are Hall Level and Manufacturing Works, Stahl Specialty Company, and Eaton Corporation.

Accessories for Permanent Mold Casting Machines

Permanent mold casting machines can be designed to interface with automatic core setting, ladling and casting removal devices. Additional options include:

- Programmable controls ($25,000)
- Water cooling of the mold station ($18,000)
- Air pressure system ($5,000).

Programmable controls permit the use of preset cycles for rotating different size molds. Water cooling of the mold station is important for maintaining constant mold temperatures and extending mold life. The air pressure system supports the hydraulic action which opens and closes the molds.

These accessories are generally available from such manufacturers as Hall Level and Stahl Specialty Company.

Permanent Molds

Permanent molds are made of fine grain cast iron or steel and may be reused many times. Mold life can vary from as few as 100 pours to as many as 250,000 pours depending on mold care, casting design and metal temperatures. Mold life for casting of gray iron is short compared with that for casting similar shapes from aluminum alloys. This is due to the higher metal pouring temperature for gray iron and the additional weight of the casting.

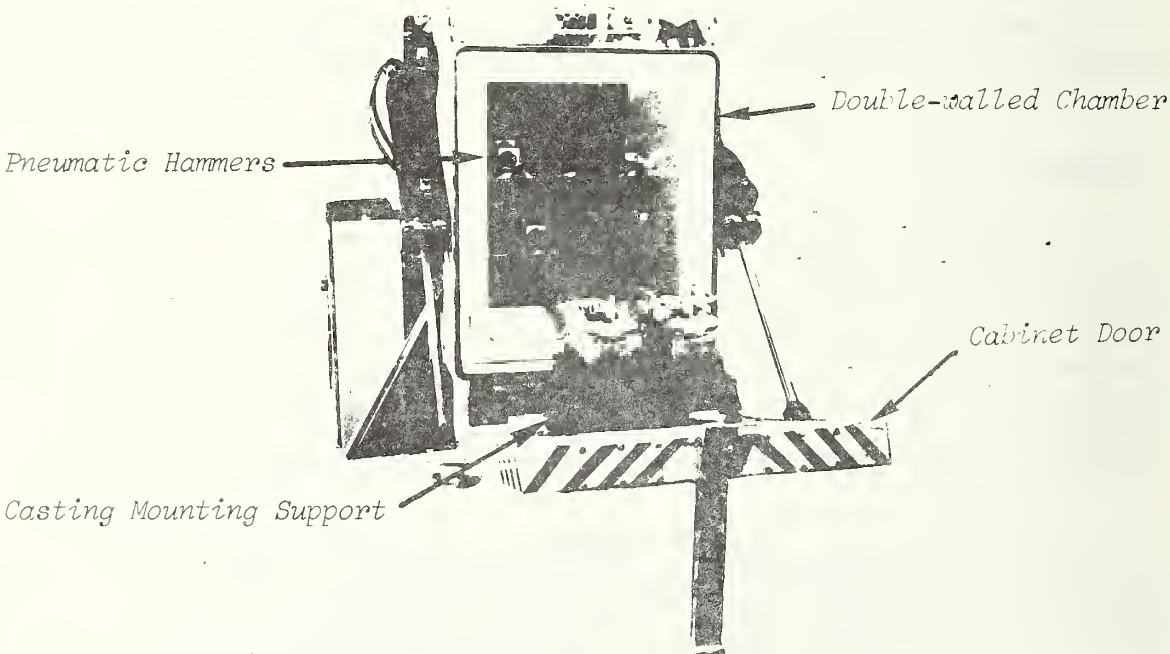
Up to six casting cavities may be contained within one mold, although two to four cavities is average for automotive components. Molds are generally purchased from specialty shops by commercial foundries while captive foundries are more likely to make the molds in-house. Each mold comes equipped with pin locators, clamping devices and ejection systems for removal of the hardened casting. Mold cost is higher than the pattern cost for sand casting. Permanent molds range in price from $10,000 to $40,000 for parts like intake manifolds.

5.5.4 Metal Cleaning Equipment

After the casting is ejected from the mold, the sand cores, gates and risers must be removed. Core removal is accomplished by means of hammering or blasting and gates and risers are removed by cutting and grinding. Price and lead time information for typical equipment is summarized in Table 4.

Core Removal Equipment

Core removal from aluminum components such as a brake master cylinder or an intake manifold is most often accomplished using an air hammer. Either an electric or pneumatic air hammer may be used. Specially designed decoring cabins are made for core removal of cylinder heads and intake manifolds. One cabin, illustrated in Figure 10, comprises a double-walled chamber with a support for the casting mounted on the inner side of the door. The castings are clamped on the support, the door is locked in place by an automatic control, and the cores are removed by means of pneumatic hammers striking the casting. Other techniques for decoring permanent mold castings include melting the core (used infrequently) and placing the casting in a shot blast cabinet. Air hammers range in price from $7,000 to $20,000.



Source: Voisin

FIGURE 10
Pneumatic Hammer Decoring Cabin

TABLE 4
Selected Metal Cleaning Equipment

Equipment	Manufacturers	Capacity	Cycle Time	Lead Time	Price
ES-1655 Shotblast Cleaning Machine	Carborundum Company Ervin Industries	265-300 castings per hour		12 months	$250,000
Air Hammer and Cabin	Voisin Company C-E Cast Equipment FMC Corporation	30 castings per hour	2 minutes		$7,000-20,000
Band Saw					$80,000
Trunion Mill	Summit Tool Corp. Republic-Lagun Tool Company				$75,000

Gate and Riser Removal Equipment

All castings are sawed to remove the gates and risers. A band saw may be used to remove the gates from an intake manifold, while a trunion mill with a nine-inch saw may be used for a master brake cylinder. Cylinder heads require a milling machine for gate and riser removal. Rough edges left by the mold parting line or sawing may be buffed or ground off. Gate and riser removal equipment ranges in price from $75,000 to $300,000.

Metal cleaning equipment is manufactured by, among others, Carborundum Company, Ervin Industries, and Voisin Company.

5.5.5 Metal Inspection and Finishing Equipment

Following removal of the gates and risers, aluminum permanent mold castings are generally heat treated and visually inspected. Because of the tendency of aluminum to develop porous areas, the castings may also be pressure tested. If a porous area or leak is found the casting may be impregnated with a sealing compound. Principal equipment costs for these various inspection and treatment processes are summarized in Table 5.

Heat Treating Equipment

Methods of heat treatment for permanent mold castings are similar to those of other casting techniques. Generally, equipment requirements are an annealing oven and a conveyor system for transporting the castings to the heat treating area. Annealing ovens range in price from $200,000 to more than $500,000, and are manufactured by Gladwin Corporation and Whiting Corporation.

Leak Tester

The leak tester is used to record very minute leaks in the walls of castings. A frequently used tester is the air underwater dunk tester where the casting is placed under water and air pressure is applied. Leak testing may be performed for every casting or on a sample basis, depending upon the foundry and the casting specifications. Leak testers range in price from $40,000 to $100,000, and are manufactured by Moak Machine and Foundry, Inc.

TABLE 5
Selected Metal Inspection and Finishing Equipment

Equipment	Manufacturers	Capacity	Cycle Time	Lead Time	Price
Annealing Oven	Gladwin Corporation Whiting Corporation	600 lbs/hour	120 minutes	8-12 months	$200,000
Dunk Type Leak Testing Machine	Moak Machine and Foundry, Inc.	100-150 castings		3-4 months	$40,000
C-Plant Impregnation System	Imprex	24-30 Intake Manifolds	12-15 minutes	5 months	$60,000

Impregnation System

The impregnation system is used to seal porous areas found in aluminum castings by the application of a tough resin material which is then absorbed into the leaks. Gray iron castings are much less susceptible to porosity. Impregnation equipment consists of an autoclave, several large baths and dip baskets to hold the castings. The price of a small system typical of that which might be found in commercial foundry is $60,000. Imprex is one manufacturer of impregnation systems.

5.6 SIZE AND STRUCTURE OF THE PERMANENT MOLD CASTING INDUSTRY

Permanent mold costing is predominatly an aluminum casting industry. In 1977 permanent mold aluminum castings accounted for 22 percent of all aluminum castings. The tonnage of such castings has increased significantly in recent years. Foundaries that do permanent mold castings may also do sand or other types of castings. Unlike die casting, permanent mold casting is not dominated by captive shops, and there is about a fifty-fifty split (see Table 6).

TABLE 6
Permanent Mold Casting Sales
(Millions of Pounds)

Type of Shop	1977	1976
Commercial	220	199
Captive	213	178
TOTAL	433	377

As described earlier, the major automotive application of permanent mold casting has been aluminum pistons. Now, however, permanent mold processes are also being used for aluminum cylinder heads, manifolds, and brake master cylinders. This has caused a great deal of activity in permanent mold facility construction in addition to interest by foreign companies such as Citroen, Fiat and Honsel Werke. Only two major foundries, Eaton and Four Cities, are making permanent mold iron castings for the auto industry.

Permanent mold facilities which supply the auto industry now exist at Doehler-Jarvis, Hayes-Albion and Dayton Malleable:

- Doehler-Jarvis. The Greenville, Tennessee plant was converted to the production of permanent mold castings in 1977, and initial production began in 1978. The 115,000 square foot plant makes intake manifolds, master cylinder housings and cylinder leads. Present employment is 150 people.

- Hayes-Albion. The Tiffin, Ohio plant houses the permanent mold casting facilities which are targeted for 18,000 tons of aluminum capacity by 1981. The foundry will be making cylinder leads and intake manifolds for the 1981 Ford Erika.

- Dayton Malleable. The Meta-Mold and Columbia plants are presently in production of aluminum permanent mold master cylinders. Additional acreage has been purchased for expanding capacity at the Columbia plant.

Additional suppliers include Stahl Specialty Company (master cylinders), Hall Machining Company (master cylinders) and Winters Industries (intake manifolds).

General Motors has a permanent mold facility in Massena, New York. Ford has an experimental facility in Sheffield, Alabama and has announced the construction of two permanent mold shops, one in Windsor, Ontario and one in Mexico. These shops will be built to give Ford hands-on experience with the permanent mold process.

5.7 TYPICAL PLANT

Aluminum permanent mold casting is generally performed by a foundry in addition to other types of casting. A newly constructed facility dedicated to permanent molding of intake manifolds is estimated to cost $6 million, $1.5 million each for the building and land and $3 million for equipment. A facility of this size (36,000 square feet) would be sufficient to produce one million intake manifolds per year, with a total employment of 70 people.

5.7.1 Plant Layout

The typical aluminum permanent mold casting plant has a core room, a main plant including the office area, and a yard. The equipment and manufacturing processes carried out in these areas are shown in Figure 11.

The plant is a large open building with a slab concrete foundation, cinderblock walls and overhead ventilation for removing the heat from the furnaces. No special underfloor construction is required, although some companies have special underfloor sand collection. Sand is allowed to sift through gratings to the floor below where it is picked up, cleansed and recycled for use. In lieu of the grating system, the sand may be swept. Storage tanks, power stations and water towers are located in the yard.

Cores are mixed, molded and hardened in the core room. The core room is separated by a wall from the main plant area because the gases used to set the resin and core are flammable.

Other principal areas inside the plant are:

- Receiving and shipping
- Casting
- Core knockout and shearing
- Casting inspection and compound application area
- Offices, laboratories, storage and maintenance.

5.7.2 Materials Flow

Principal materials which are handled in an aluminum permanent mold casting facility include aluminum ingots or scrap, raw sand, various binders and chemicals. The flow of each type of material through the plant layout illustrated in Figure 11 is described below.

Aluminum

Aluminum is received in ingots or compressed scrap and stocked near the melting area until it is required for charging the furnaces. Once it is charged into the central melting furnace it is repeatedly checked for proper alloy content and structure. The hot metal is transferred by ladle or by a tap to the holding furnace to free the melting equipment for steady production of molten metal. When

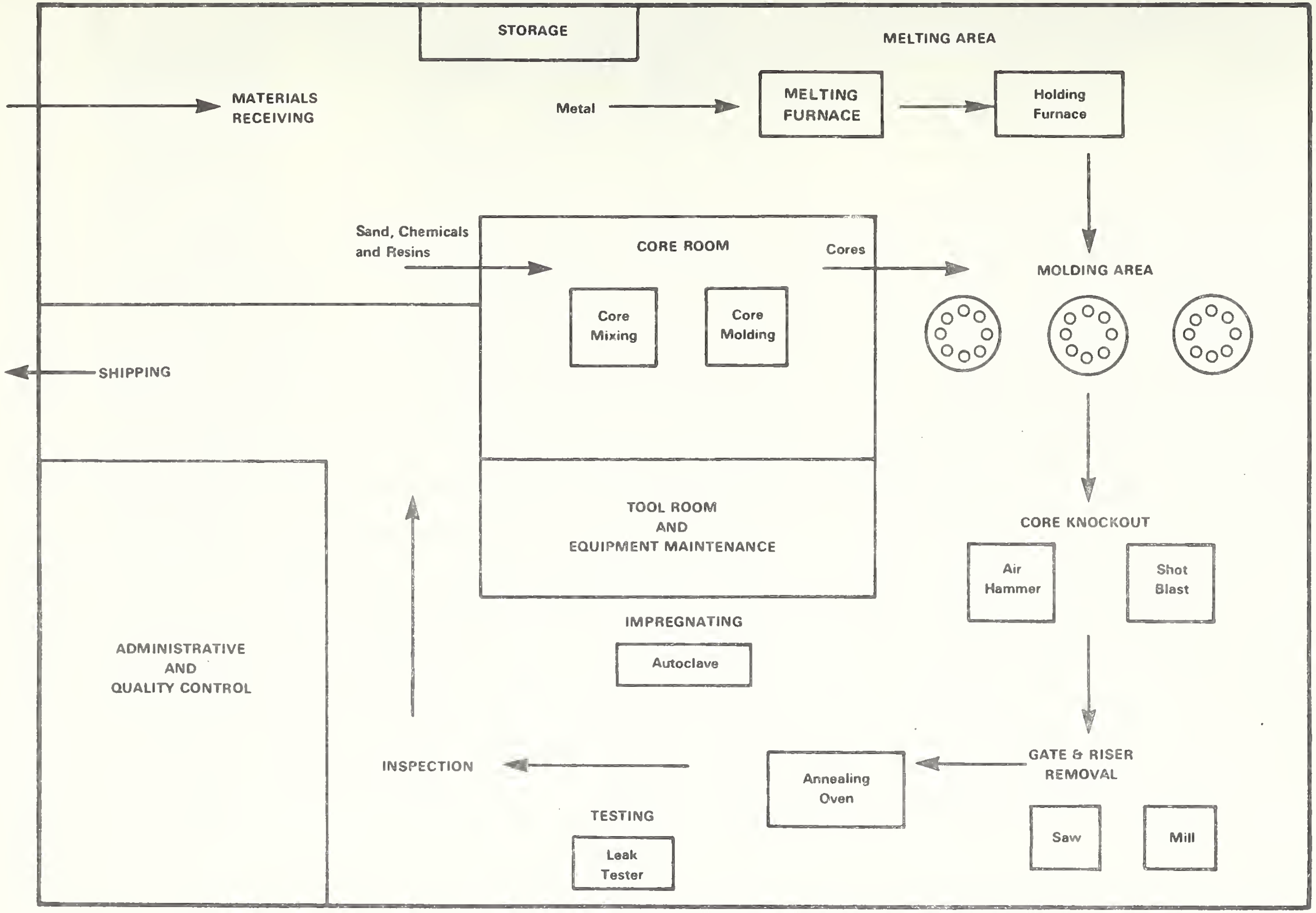


FIGURE 11
Typical Permanent Mold Casting Plant Layout

required, the hot aluminum is poured manually or automatically into the permanent molds on a single station or rotary casting machine. If a rotary machine is used, the molds are automatically indexed to the pouring area.

When cooled, the aluminum which is now a casting, is ejected from the permanent mold into a casting catcher and transported to the core knockout area where the sand core is removed. Following core removal the casting receives a preliminary inspection and then the gates and risers are removed by sawing or milling, depending on the type of component. Following the removal of gates and risers the casting may be heat treated or sent directly to the leak tester where it is checked for porous areas. If leaks are found the casting is placed in the autoclave and impregnated with a sealing compound. The castings receive a final inspection, are packed in wooden crates and loaded into trucks for shipping.

Sand, Binders & Chemicals

Raw sand may be stored in a silo and pumped directly into the core room or stored inside the plant. Inside the core room, the sand is passed over the coils of a heater/cooler to normalize the sand temperature and humidity before it passes into the core mixer. In the core mixer, the sand is mixed with various binders and resins, depending upon the coremaking process to be used. From the core mixer the sand passes to the coremaking or blowing machine. Sand is rapidly blown into the core box in a stream of compressed air. Then the core is hardened by the Isocure process.* Finished cores are manually or automatically placed in the mold before it is closed to receive the molten metal. When the casting has solidified the sand cores are removed with an air hammer or a shot blast machine and the sand is recovered for processing and re-use.

5.7.3 Capital Requirements

Capital requirements for a complete aluminum permanent mold casting facility include the land, building, equipment and miscellanious support facilities. The total investment depends on the production level of the foundry. Total capital requirements for a foundry producing one million permanent mold cast intake manifolds is estimated to be approximately $6 million, although it can run as high as $12 million.

* Other processes such as the hot box method may be used for core preparation.

Building and Land Requirements

Twenty acres of land is sufficient for a foundry of this size. A building adequate to house a specialized permanent mold foundry producing one million intake manifolds per year includes:

- Cinderblock construction with vents for air circulation and corrugated steel ceiling
- Six- to eight-inch concrete floor
- Overhead ventilation system
- Storage areas for stacked aluminum ingots, aluminum scrap, chemicals, and crates
- Office area (air conditioned)
- 36,000 square feet (building dimensions 240 ft x 150 ft)
- Industrial zoned land with electric power and gas hook-ups, good roads and access to major highways and airports.

Exterior facilities include:

- Evaporative water cooler
- Silo
- Power station
- Propane or natural gas tank
- Settling tank
- Parking lot.

Estimated building and land costs are summarized in Table 7.

TABLE 7
Building and Land Requirements for
Permanent Mold Casting Plant

Capital Requirement	Cost
Building (36,000 sq ft @ $40/sq ft)	$1.5 million
Land (20 acres @ $75,000/acre)	$1.5 million
TOTAL	$3.0 million

Equipment Requirements

Equipment requirements for a typical permanent mold casting plant are listed in Table 8. The permanent molds and rotary casting machines are the largest single expense, totaling nearly $1 million. Other major equipment includes furnaces, core mixing and molding machines, core knockout equipment, testing and curving machines, fork trucks, conveyors and pollution controls. Total equipment costs are estimated at $3 million.

5.7.4 Labor Requirements

Labor requirements for a two-shift aluminum permanent mold casting plant are summarized in Table 9. Total plant employment is estimated at 70 including 62 production and 8 administrative personnel. Many of the production operations in the plant are assumed to be automated such as metal pouring, removal of the castings from the molds and most of the transportation of castings around the plant. The plant is assumed to be non-union. This provides the added flexibility of assigning workers where they are needed on each shift, with some job overlapping.

Administrative personnel handle sales, payroll, bookkeeping and all administrative activities necessary to run the plant. The sales manager travels frequently to visit auto manufacturers and obtain new orders.

5.7.5 Energy Requirements

The energy consumption in a permanent mold casting operation is predominantly in the melting operation. The amount of energy consumption per ton of aluminum consists of the energy to melt aluminum (about 250 kwh/ton) plus extra energy due to the inefficiency of the furnaces. Table 10 gives the efficiencies for some aluminum furnaces.

TABLE 8
Equipment Requirements For An
Aluminum Permanent Mold Casting Facility

Equipment	Quantity	Unit Price (Thousands)	Total Price (Thousands)
CORE ROOM:			
Combination Core Mixing/Molding Machine	5	$ 85	$ 425
Sand Hoppers	5	3	15
Gas Scrubber	1	15	15
Air Compressor	1	30	30
Core Racks	50	1	50
MELTING AREA:			
Central Melt Furnace	1	320	320
Holding Furnace	2	75	150
Ladles	1	10	10
Crane	1	20	20
CASTING AREA:			
Permanent Mold Casting Machines	2	300	600
Molds	20	50	1,000
CORE KNOCKOUT:			
Grinders	2	8	16
Shot Blast Cabinet	1	30	30
Saws	2	7	14
TESTING AND CURING:			
Annealing Oven	1	100	100
Leak Tester	2	40	80
Impregnation System	1	60	60
MISCELLANEOUS:			
Fork trucks, conveyors, special ventilation			100
Dust collectors and pollution control equipment			50
TOTAL			$3,085

TABLE 9
Labor Requirements for Two-Shift
Permanent Mold Casting Plant

Skill	Number
ADMINISTRATIVE:	
Plant Manager (Day)	1
Night Manager	1
Accountant	1
Sales Manager	1
Secretary/Receptionist	1
Accounting Clerks	2
Janitor	1
PRODUCTION:	
Department Foremen	4
Furnace Tenders	6
Core Molding Operators	8
Core Setters	4
Casting Machine Operators	6
Core Knockout Machine Operators	6
Gate and Riser Removal and Rough Machining	6
Leak Test Operators	4
Annealing Oven Operators	4
Impregnation System Operators	2
Quality Control Inspectors	2
Equipment Maintenance Mechanics	2
Equipment Maintenance Assistants	2
Fork Lift Operators	6
TOTAL	70

TABLE 10
Efficiencies of Aluminum Furnaces

Type of Furnace	Efficiency of Melting
Induction	50-65%
Reverbatory	20-30%
Immersed Crucible	40%
Electric Wet Bath Reverbatory	60%

An efficient furnace would require about 400 kwh per ton to melt aluminum. A planned melting capacity of 1.5 tons per hour would require 800 kw of power. Power requirements for holding furnaces are around 150 kw per ton. The only other significant energy requirement would be plant heating, and this would depend on location.

5.8 KEY ISSUES

Key issues in permanent mold casting include technology advances from competing processes and the need for impregnation of aluminum castings.

5.8.1 Competition from Other Casting Techniques

Permanent and semi-permanent mold casting are useful for large production runs of intricate automotive components requiring expendable cores or for use where the alloy is not easily die cast. Permanent mold casting is more versatile than die casting but slower in production. It is more costly than sand casting but capable of producing parts free from burnt-in sand. The use of permanent mold casting is expected to increase over the next seven to eight years as aluminum usage in the automobile increases. After that time, however, use of the process may decline due to technology advances in sand and die casting techniques. Examples of technology advances which may threaten permanent mold casting include the following:

- High Speed Sand Casting Techniques. A new sand casting technique developed in Sweden, the Disamatic technique, permits high speed fully automatic sand casting in just six seconds. This technique may make sand casting more competitive with permanent mold casting for high volume components.

- Developments in Die Casting Techniques. As the automotive industry becomes more aware of the savings that are possible by designing parts with casting in mind, changes are taking place in engine components. Gradually, sand cores are being "designed out" of high volume castings. The ultimate goal is to develop die casting techniques appropriate for aluminum engine parts. This technology will probably take 7 to 8 years to evolve.

Unlike the growth expected for aluminum, gray iron applications of permanent mold casting are expected to continue at the current low rate. The only potential for growth in gray iron permanent mold castings is a possible improvement in the rotary engine.

5.8.2 Need for Impregnating Aluminum Castings

The shift from iron to aluminum castings for vehicle weight reduction has increased the requirements for impregnation treatments. Whereas an iron part might have had a minimal porosity problem, a shift to aluminum can lead to unacceptable leakage rates which require corrective steps.

Sealing systems are being used to impregnate aluminum components which handle gases and fluids such as cylinder heads, intake manifolds and master cylinders. The past half dozen years have seen a dramatic shift of attitudes in aluminum casting. Porosity once was a hush hush subject because of the lack of real control over it. Now, most everyone realizes the varying percentages of parts made under the most careful and professional metal forming practices will leak. The problem is to make the impregnation system more easily adaptable to the high speed automotive assembly lines.

6. DIE CASTING

6.1 GENERAL

Die casting makes possible the economical high quantity production of intricate castings at a rapid rate. Such castings, which may comprise various holes, recesses, screw threads, etc., are characterized by high dimensional accuracy, good surface finish, and economy of metal; they require little or no final machining. The principle on which die-casting processes are based consists of forcing molten metal into a mold (the "die") under considerable pressure. Metals which are commonly die cast include aluminum, zinc and magnesium. Automotive parts which are commonly die cast include power steering pump and rack and pinion power steering housings and decorative trim.

6.2 MAJOR TYPES OF DIE CASTING

Die castings are usually distinguished by:

- Type of machine used
- Kind of metal used.

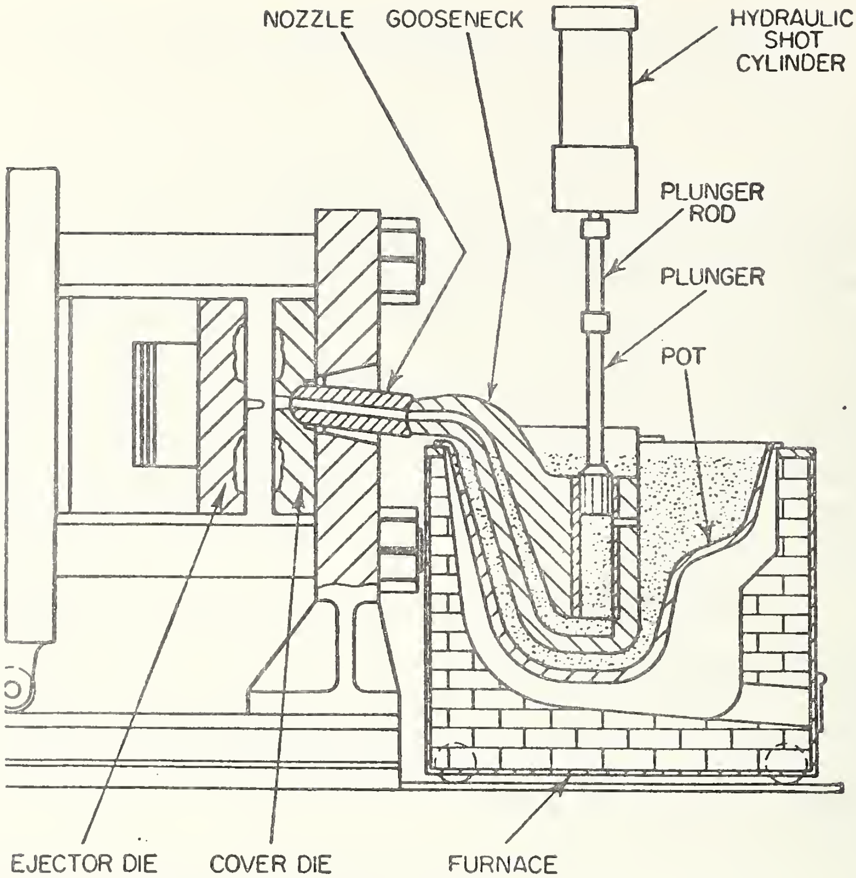
6.2.1 <u>Type of Machine</u>

There are two basic types of machines used to manufacture automotive parts and components. They are:

- Hot chambered machines
- Cold chambered machines.

Hot Chambered Machines

In the hot chambered or "gooseneck type" machine shown in Figure 1, the injection mechanism is immersed in a molten metal bath in a furnace attached to the machine. Operation of the machine is as follows. The plunger is raised and opens a port allowing molten metal to fill the cylinder. The plunger then moves downward closing the port, forcing metal through the gooseneck and nozzle into the die. The molten metal is maintained under pressure in the die until



Source: American Die Casting Institute

FIGURE 1
Hot Chambered Machine

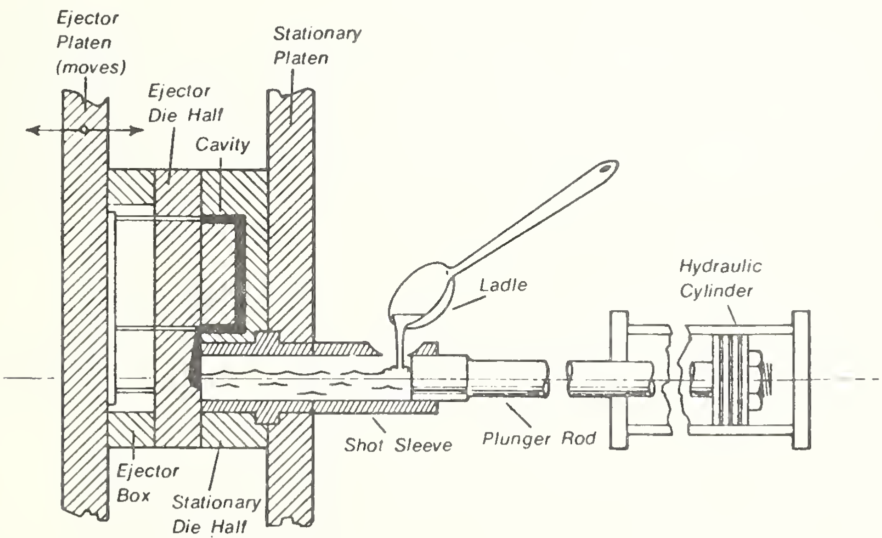
it solidifies. Pressures applied can range from 1,500 to 2,000 psi. Once solidified, the die is forced open and the casting is ejected from the die.

One of the problems with hot chambered machines is that there is appreciable entrainment of air in the metal during injection, although this can be diminished by close control of the injection speed.

Since the gooseneck and pot are made of iron and since most metals react with iron at elevated temperatures, only low melting point metals such as lead, tin, and zinc may be cast by this method. Hot chambered machines are rapid in operation and the plunger can be adjusted to apply the pressure required to force molten metal into the die to capture even the finest detail. Hydraulic pressure cylinders (occasionally air) are used to actuate the plunger.

Cold Chambered Machines

Cold chambered machines differ from hot chambered machines primarily in one respect: the injection plunger and cylinder are not submerged in molten metal. As shown in Figure 2, the cold chambered machine uses a ladle to transfer the molten metal from a melting pot to the cold chamber of the die machine. The metal is forced under very high pressure into the die cavity. This is usually accomplished by a hydraulically operated plunger. Injection pressures usually range from 3,000 to 10,000 psi for both aluminum and magnesium alloys and from 6,000 to 15,000 psi for copper base alloys. The metal is kept under pressure until it has solidified, at which time the core is retracted, the mold is opened and the finished casting is ejected from the cavity by the ejection pins.



Source: American Die Casting Institute

FIGURE 2
Cold Chambered Machine

In cold chamber operations the molten metal is usually maintained at constant temperature in an adjacent holding furnace of the bale-out type;* transfer of successive shots to the machine chamber can be accomplished either by hand or by automatic pumping devices, including the use of vacuum suction and air displacement systems. One arrangement for metal supply utilizes a single melting furnace feeding holding units at several die casting machines through a system of heated troughs. Holding furnaces may be of the electrically heated or fuel-fired crucible type; one modern method of maintaining temperature uses immersion heating.

Operation of a cold chambered machine is somewhat slower than a hot chambered machine primarily because of the ladling operation. Cold chambered machines are used for higher melting point casting alloys such as aluminum and magnesium because of the differences mentioned earlier. When this technique is used, plunger and cylinder assemblies are less subject to attack because they are not submerged in the molten metal. In addition, castings are also less prone to entrapped air (because of the much higher injection pressures). A higher standard of soundness also ensues from the smaller amount of liquid and solidification shrinkage occuring within the die.

It should be noted, however, that in a cold chambered machine there must always be more molten metal poured into the chamber than necessary to fill the die cavity. This sustains sufficient pressure to pack the cavity solidly with casting alloys. Excess metal is ejected with the casting "gate" and is part of the complete shot.

6.2.2 Metals Used

The metals which are most commonly die cast for automotive purposes include zinc, aluminum and magnesium.

Zinc

Zinc alloys account for about one-half of the total tonnage of die castings produced, because they present the most favorable combination of low cost per casting, good physical properties, and ease of casting and finishing. The average melting point of zinc alloys is 715°F. Casting is commonly done at temperatures of 750°F to 800°F. Speeds up to 500 casting cycles per hour can be obtained.

* Metal is manually "baled-out" or ladled.

Aluminum

Aluminum alloys rank second in die casting use. In some cases they cost no more than zinc castings of the same dimensions. The primary advantage is light weight. Die casting rates are lower than for zinc, however, commonly from 80-200 die fillings per hour.

Magnesium

Magnesium, while not widely used, is a strong future candidate for the die casting of automotive parts and components. Magnesium's principal advantage over zinc and aluminum is its light weight. For comparable parts, magnesium is about one-fourth the weight of zinc, and two-thirds the weight of aluminum.

6.3 ADVANTAGES AND DISADVANTAGES OF DIE CASTING

Die casting is important to the automotive industry because it has significant advantages over other casting processes. For example, compared to sand casting, described previously, die castings are produced more rapidly in dies which make thousands of die castings without replacement. The die castings can also be made with thinner walls. These features of die casting are significant to the automotive industry which is high production oriented and which is also in the midst of lightening vehicles through the use of thinner wall castings and lighter weight materials. Other advantages of die casting are:

- They require much less machining. Die castings are produced as almost completely finished parts. Thus, the investment in inventory and factory floor space is reduced to a minimum.
- They allow much more complex shapes to be made than any other casting technique except investment casting. Die casting, because of its high injection pressure, allows greater length-to-thickness ratio and greater dimensional accuracy.

The primary drawbacks of die casting are the size of the part that can be die cast, the cost of facilities and equipment required for die casting, and the metals that can be die cast:

- Die casting is usually constrained to parts under 50 pounds.

- The facilities, cost of the machine, the auxiliary equipment and the dies are relatively expensive. Thus, because die castings are relatively small, large quantities of castings are required for the process to be economical.

- With few exceptions, commercial use of the process is limited to metals having melting temperatures no higher than those of the copper-base alloys. Thus, iron and steel parts cannot be die cast.

In addition to the above, welding of die cast parts is also a problem, although some recent advances have been made in this area. Entrapped air is the principal problem, preventing the structural welding of die cast parts and generally weakening the discrete element's strength.

6.4 AUTOMOTIVE APPLICATIONS OF DIE CASTING

Most present automotive applications of die casting involve zinc, primarily thin-walled zinc. However, as the auto manufacturers continue to lighten their vehicles, aluminum and magnesium die cast parts are likely to be used more and more.

6.4.1 Aluminum Die Cast Parts and Components

Even though there are many aluminum die cast automotive parts and components at present, the American Die Casting Institute is predicting record-breaking growth in aluminum die casting sales right through 1985. The reason for this prediction is that the auto manufacturers, to meet the mandated goal of 27.5 miles per gallon by 1985, will increasingly have to look toward aluminum. Die casting is the least expensive method overall for mass production of aluminum castings. As described in the previous section, die casting is capable of producing castings with very thin cast sections, excellent dimensional accuracy, fine part detail and surface finish, and superb mechanical properties—all of which are important in casting aluminum. Die casting aluminum is also not new. The American Motors Rambler Classic made in 1960 had a die cast 6-cylinder aluminum block. More recently, Vega and Corvair engines were aluminum die cast but with cast iron heads (in order to maintain rigidity). Though these products are not on the market today, their demise was not due to the use of aluminum or die casting. Potential applications of alumium die cast parts together with their weight savings over iron are shown in Table 1.

TABLE 1
Potential Applications of Aluminum Die Cast Parts

Parts	Iron Weight (lbs)	Aluminum Weight (lbs)
Intake Manifold	8-40	4-20
Engine Block	180-260	30-70
Clutch Housing	9-12	3-4
Brake Drum	12-20	4-8
Water Pump	4-12	1.5-5
Transmission Housing	30-50	11-18
Oil Pump Housing	3-5	1-2
Alternator Housing	N/A	2-3
Thermostat Housing	4-7	1-2

A listing of those parts and components which are presently die cast out of aluminum on a limited basis is as follows. Additional components are identified in Figure 3.

- Rack and Pinion Power Steering Gear Housing. This part, cast in one piece, was introduced on the 1978 Ford Fairmont/Zephyr producing a weight savings of 4.5 pounds per car

- Power Steering Pump Housing. Also introduced in 1978, this aluminum die cast part has resulted in a savings of 5.2 pounds per car over 1977 by replacing the cast iron housing used in that year. The part was introduced on several Ford models.

Figure 4 shows actual components which are die cast from aluminum.

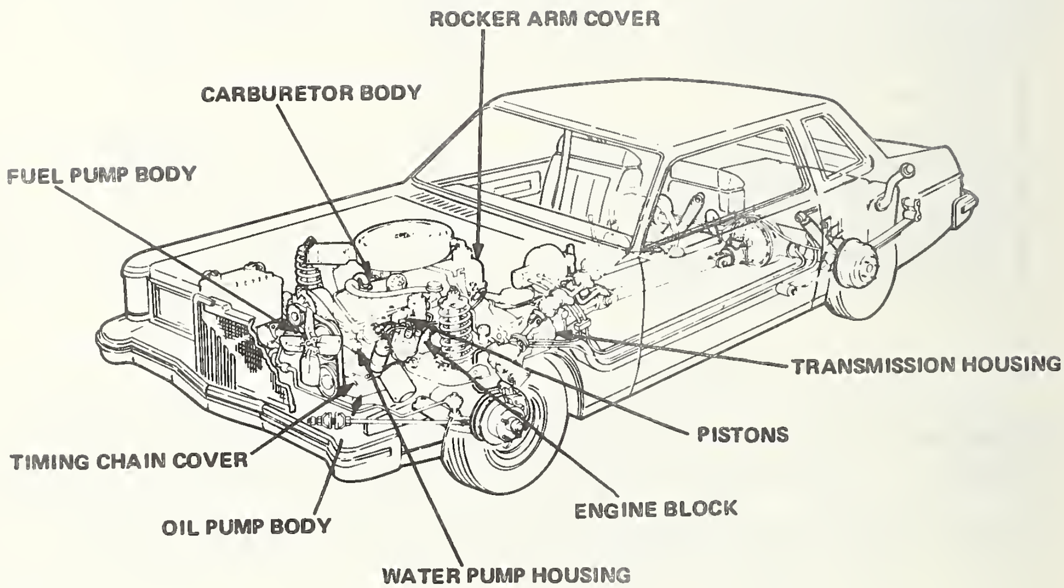


FIGURE 3
Schematic Diagram of Automobile Showing
Parts and Components Which Are Die Cast Out of Aluminum

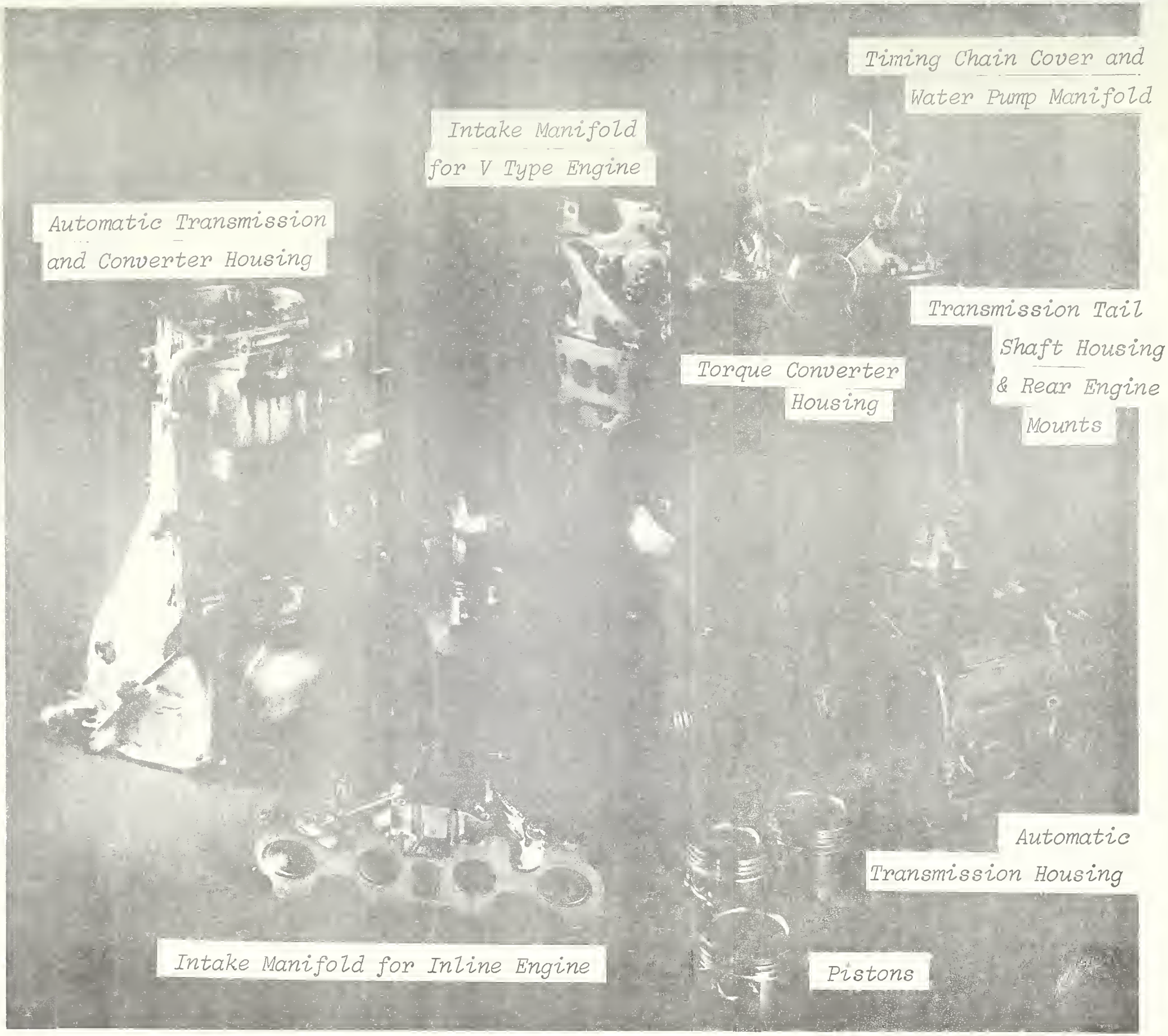


FIGURE 4
Examples of Aluminum Die Cast Automotive Parts and Components

6.4.2 Zinc Die Cast Parts and Components

Zinc has been the primary die cast material in automobiles for several years, used in such applications as rear lamp bezels, head lamp bezels, door and window handles, exterior molding and grille work. (See Figure 5.) While zinc is still the predominant die cast material, thin-wall castings are being employed instead of conventional castings. The reason for this change is the loss of many zinc automotive applications to plastics. Only through thin-wall zinc die casting technology can zinc compete with plastics for some automotive applications.

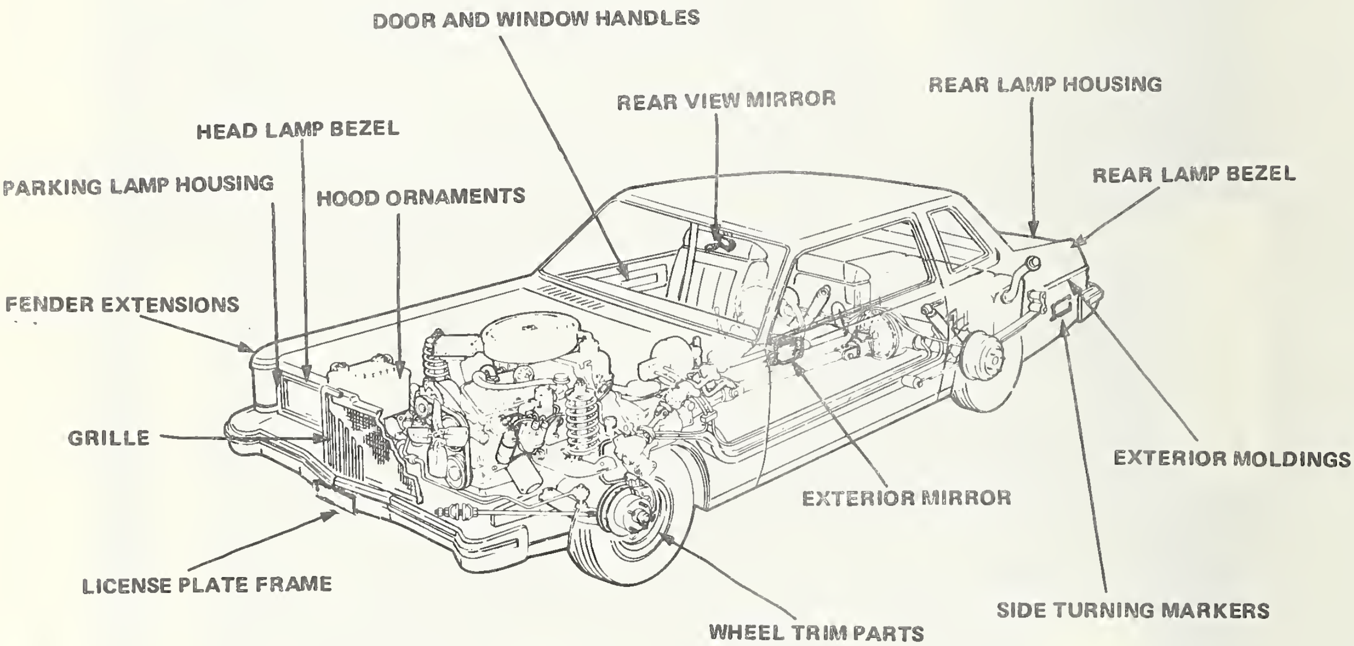
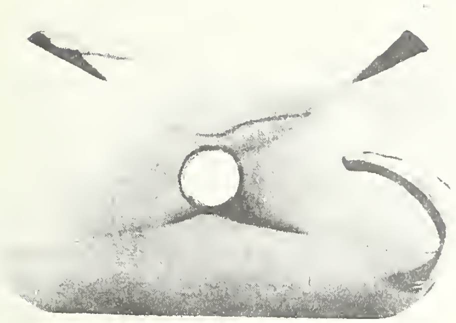


FIGURE 5
Automobile With Zinc Die Cast Components

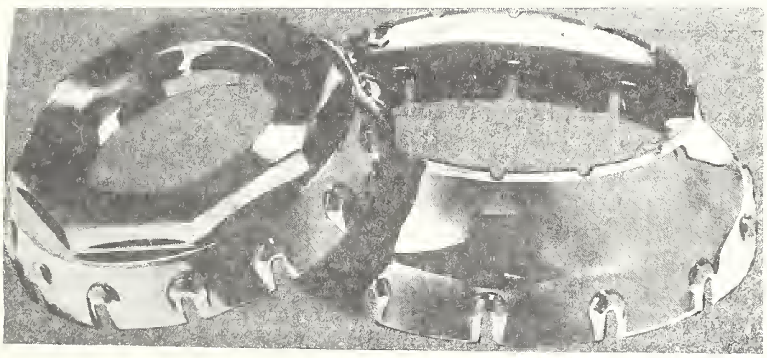
It appears that thin-wall technology is also working. In 1979 the number of thin-wall zinc die casting applications increased to 150 compared to some 70 applications in 1977. Some examples of thin-wall zinc die castings by manufacturer are given below.* Photographs of typical thin-wall zinc die casting applications are provided in Figure 6.

* From Zinc Institute 1979 Status Report on Thin-Wall Zinc Automotive Die Castings.



EXTERIOR MIRROR HOUSING

EXTERIOR MIRROR BASE



SIMULATED WIRE WHEEL HUB PARTS

Source: Automotive Engineering, March, 1977

FIGURE 6
Thin-Wall Zinc Die Castings

- Chrysler. Chrysler has more than 22 components spread among ten 1979 car models. Chrysler began using thin-wall zinc die castings in early 1972 for fender extensions. While these particular applications have for the most part not been included in the design criteria used for today's shorter, lighter cars, this experience did give Chrysler engineers the basis for specifying additional thin-wall designs. License plate frames, exterior mirrors, grille frames and headlamp bezels are among the components specified in thin-wall zinc.

- General Motors. General Motors has nearly 75 types of thin-wall applications covering 13 car models. Applications span all the way from GM's most expensive car, the Cadillac, to the Chevy Nova, one of its least expensive models. GM engineers used experience with thin wall in previous car models as the basis for specifying the same application in the 1979 models. For example, there are ten thin-wall zinc die cast applications for GM cars that carry over from 1978 models. Among the most significant are exterior door handles and rear view mirrors for all cars produced by GM. License bezels, headlamp bezels, grille frames, and front and rear fender extensions are other applications.

- American Motors. Emphasis at American Motors continues to be on the use of thin-wall zinc die castings for the front and rear lamp housings of the Pacer sedan and station wagon. New this year are applications for the Spirit and Concord models.

- Ford. At Ford, the use of thin-wall zinc die castings continues to be emphasized for top-of-the-line cars. For example, Ford's new LTD series features thin-wall zinc grille surrounds, hood ornaments, headlamp bezels, side turning markers, rear lamp bezels and wire wheel covers. These applications are used for the two- and four-door LTD sedans, the LTD station wagon and the LTD Landau. These thin-wall applications are examples of how Ford is working to convert all exterior zinc die cast components to thin-wall.

6.4.3 Magnesium Die Cast Parts and Components

As is evident from Figure 7, the amount of die cast magnesium in domestic cars is at present negligible. In fact, as shown in the figure, the only large magnesium component in domestic cars is the case for the manual transmission in Chrysler's front wheel drive Dodge Omni and Plymouth Horizon. Furthermore, the part is not even made in the U.S.; it is made by Volkswagen West AG in Western Germany and sold to Chrysler.

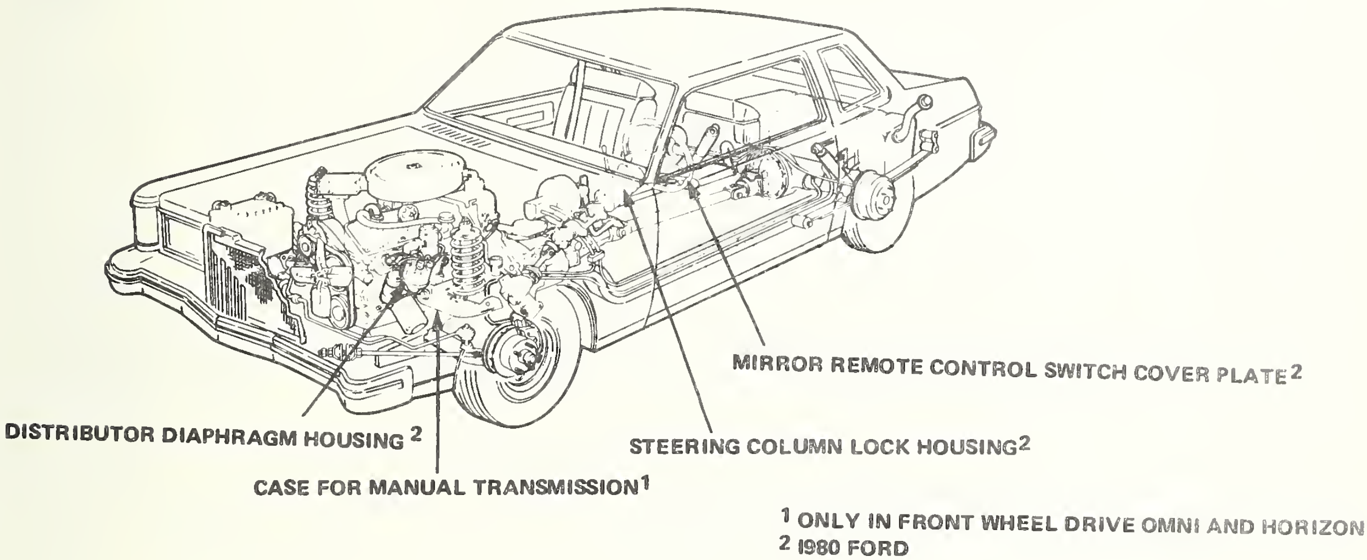


FIGURE 7
Automobile with Magnesium Die Cast Parts

With advances in die casting technology however, and the potential for magnesium in reducing vehicle weight, it is likely that we will be seeing more magnesium die cast components over the coming years. Ford, for example, is already preparing to introduce die cast magnesium steering column lock housings on some passenger cars in 1980 as well as:

- Magnesium die cast mirror remote control switch cover plates
- Magnesium die cast distributor diaphragm housings.

Other parts which Ford is considering for magnesium die casting include window regulator handles, brake master cylinders, door handles and various small to mid-size components. Whether magnesium will be used in place of aluminum and/or zinc, however, will depend on the tradeoff between the weight savings offered by magnesium versus its higher cost.

6.5 EQUIPMENT REQUIRED

The range of equipment required for a die casting plant is not as varied as for other casting processes. Equipment required for die casting includes:

- Melting and pouring equipment
- Die casting machines
- Machining equipment
- Support equipment.

Each type of equipment is described below. Prices are shown in Table 2.

TABLE 2
Die Casting Equipment

Equipment Type	Manufacturers	Capacity	Cycle Time	Lead Time	Price
MELTING AND POURING EQUIPMENT Melting Furnaces	Westinghouse ASEA Ajax Magnethermic	5,000 lb/hr	1 hour	4-6 months	$300,000
Holding Furnaces	Lindberg Sunbeam Ipsen MPH Industry	5,000 lb/hr		4-6 months	$ 75,000
Automatic Ladle	Lindberg Whiting Industrial				$ 15,000
DIE CASTING MACHINES Die Casting Machine Hot Process	Lester KUX B&T Engineering Ex-celto	600 tons	1/2 minute	28-30 weeks	$175,000
Die Casting Machine Cold Process	Lester KUX B&T Engineering Ex-celto	600 tons	1 minute	28-30 weeks	$175,000
MACHINING EQUIPMENT Trim Presses	Tabor Dessano Radial Ex-Cell-O	50 tons	12 seconds	14-16 weeks	$ 30,000- 50,000
Drill Presses					$ 50,000
DIE CASTING SUPPORT EQUIPMENT Fork lift	Towmotor Clark-Ross				$ 20,000- 60,000

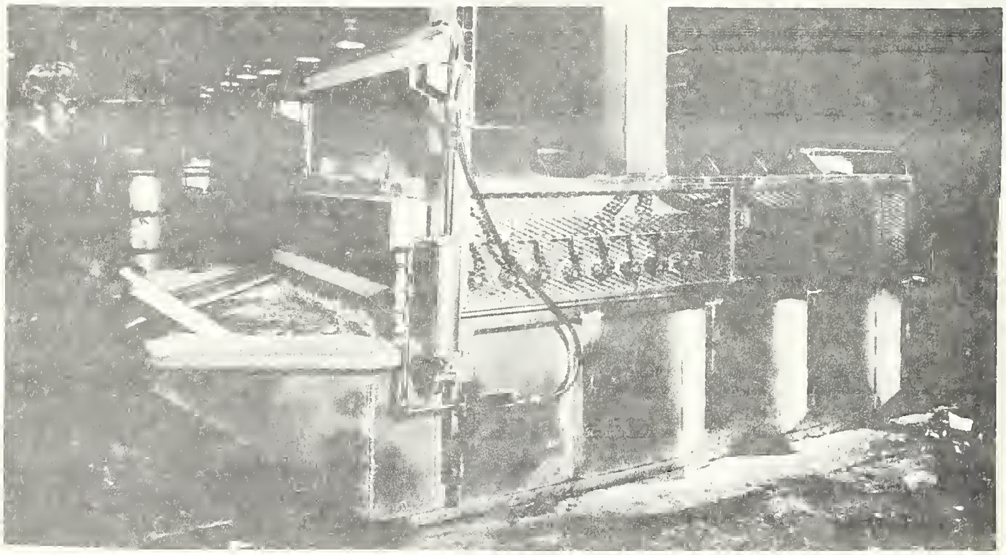
6.5.1 Melting and Pouring Equipment

Melting and pouring equipment includes furnaces and ladles for melting, holding and transferring the hot metal.

Melting Equipment

The requirements for furnaces are metal-specific and are similar to other casting processes. Aluminum may be melted in a cupola, reverbatory or an induction furnace. Older die casting shops utilize reverbatory open hearth furnaces, while new facilities often select the channel induction type furnace. A typical channel induction furnace will melt 5,000 pounds of aluminum per hour if operated full time. Holding furnaces have larger metal holding capacities and are designed to maintain the metal at a proper pouring temperature. Melting furnaces range in price from $300,000 to $350,000. Holding furnaces range in price from $75,000 to $150,000. Leading manufacturers of melting and holding furnaces include Westinghouse, ASEA, and Lindberg.

Figure 8 shows an electric reverbatory furnace which is in use in a number of aluminum die casting foundries. The furnace uses electric radiant heating elements as the source of heat to melt up to 1,200 pounds of aluminum ingots and scrap metal per hour.



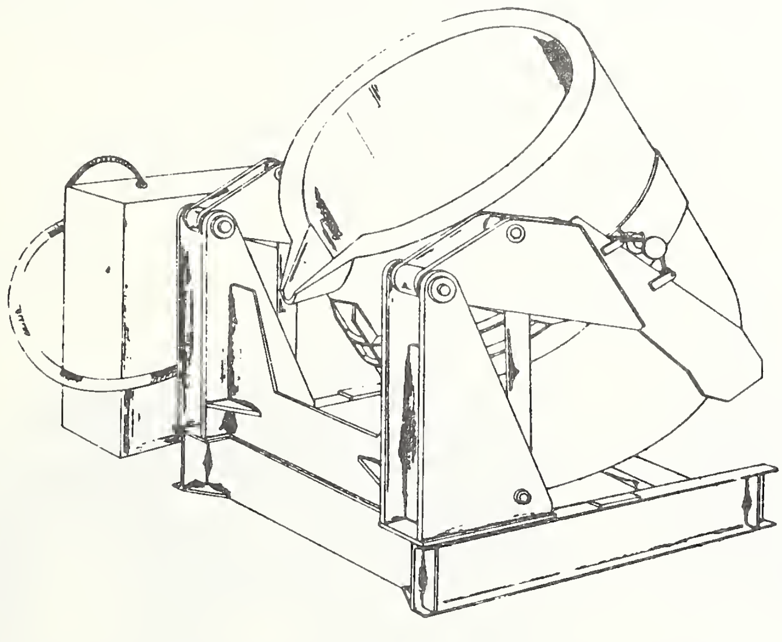
Source: Frank W. Schaeffer, Inc.

FIGURE 8

Electric Reverbatory Furnace for Melting Aluminum

Pouring Equipment

Modern automatic pouring systems are used instead of the traditional ladles in today's die casting shops. Metal may also be poured from a channel on the furnace into a ladle and transported on a fork lift truck. Automatic ladles, such as the one illustrated in Figure 9, are used to transport the metal from the melt furnace to the holding furnace. The ladle is fitted on a tilting stand and has control cabinets for a hydraulic pump, gas and air supplies, and a temperature controller to maintain the melt temperature at the desired level. Automatic pouring equipment ranges in price from $15,000 to $35,000. Whiting Corporation and Lindberg are two manufacturers of automatic ladles.



Source: The Die Casting Book by Arthur Street, 1977

FIGURE 9

Hydraulically Operated Ladle

6.5.2 Die Casting Machines

Most machines today have horizontal frames with in-line injection mechanisms such as the hot chambered pressure die casting machine illustrated in Figure 10. Over recent years, the main developments have been in the size and capacity of die casting machines, the replacement of hand-ladling by various systems of mechanized metal metering, and increasing sophistication in hydraulic injection systems. Features which are provided on most machines include:

- Adjustable die height
- Operator control system for central pushbutton control of the machine
- Automatic lubrication system which supplies a metered amount of lubricant to all moving parts of the die locking assembly with each machine cycle
- Automatic core pull
- Automatic casting ejection
- Water die cooling system
- Variable shot stroke.

Hot chambered and cold chambered die casting machines differ very little in price but greatly in cycle time, with the cold chambered machine being far slower. The average price of a 600 ton hot chambered machine is $175,000 and that of a cold chambered machine $165,000. The price of a die casting machine may range as high as $1 million for a machine with a 3,000 ton clamping pressure.* These prices are exclusive of dies which can cost as much as $500,000 or more depending on the die size and complexity. A typical die would cost approximately $200,000.** Leading U.S. manufacturers of die cast machines are Kux, Lester, Wicks and Ex-Cell-O. Figure 11 shows a photograph of an Ex-Cell-O die casting machine.

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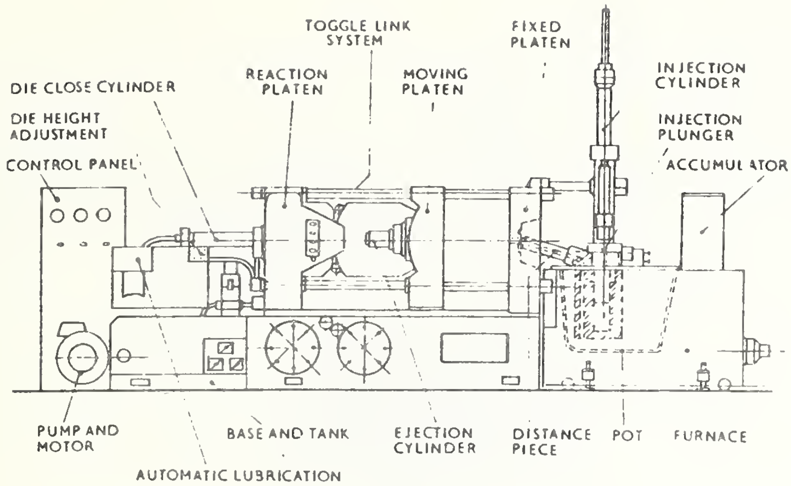
* Machines of this size typically be found in captive shops for making larger die cast automotive parts.

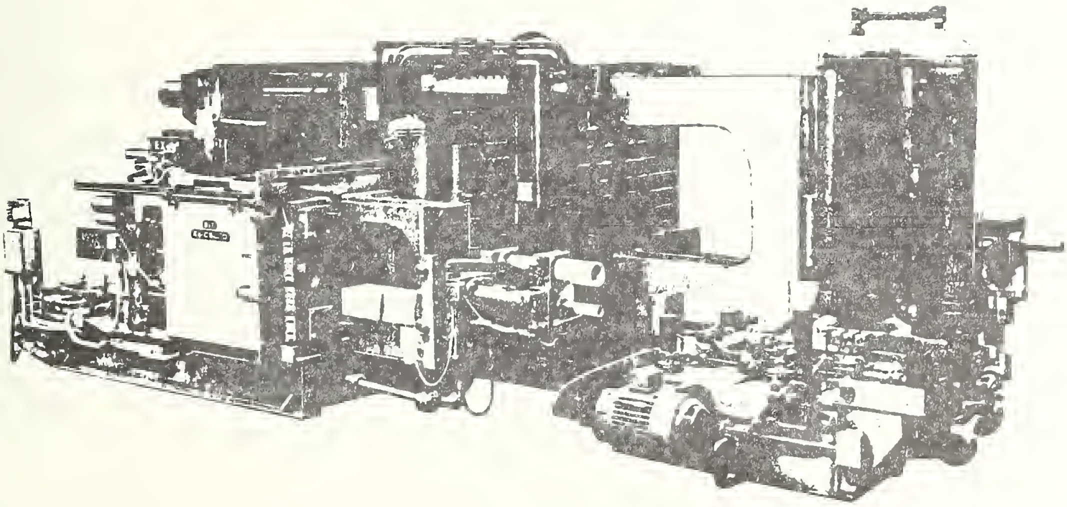
** In general, the rule of thumb is that, for the same part, a die costs approximately four times as much as a permanent mold.



Source: The Die Casting Book, by Arthur Street, 1977

FIGURE 10

Basic Parts of the Hot Chambered
Pressure Die Casting Machine

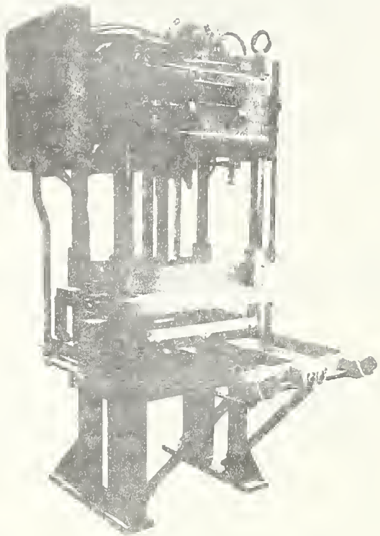


Source: B&T Die Casting Machinery Brochure, March 1979

FIGURE 11
Die Casting Machine

6.5.3 Machining Equipment

For many applications of die casting, light machining is required before the die casting is ready for use. Equipment required for such machining includes a trim press, as shown in Figure 12. The trim press is used to remove flash from the casting.

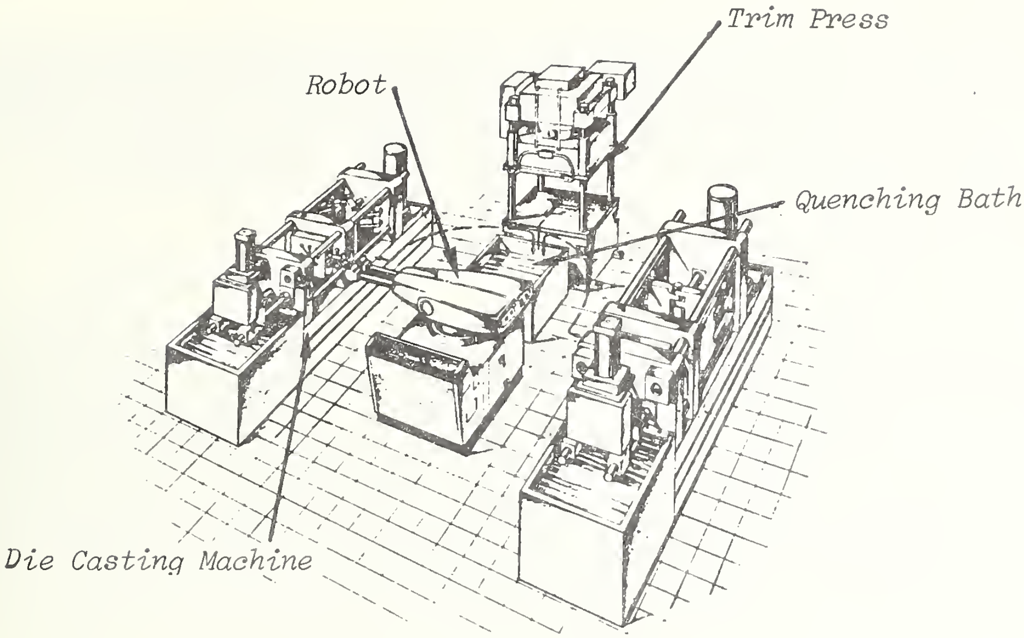


Source: Die Casting Engineer, May/June, 1979

FIGURE 12
Ex-Cell-O Trim Press

Other machining equipment required in a die casting foundry may include drills, grinders and milling, tapping and reaming machines. The amount of machinery required depends upon the accuracy needed for the casting. In a typical casting shop, trim presses and drills would be adequate for removing flash and other superfluous metal. Trim presses retail for approximately $120,000 (including cutting dies) and drill presses for $50,000. Manufacturers include Bridgeport Corporation, Kearny and Trecker, and Ex-Cell-O.

Transferring a casting from the die cast machine to a trim press may be accomplished by operators using conveyors, or may be completely automated with the use of robots, as shown in Figure 13. Here an industrial robot unloads the die casting machine, quenches the casting and loads it into a trim press.



Source: The Die Casting Book by Arthur Street, 1977

FIGURE 13

Schematic Layout Showing an Industrial Robot Unloading Two Die Casting Machines, Quenching Component and Loading to a Trim Press

6.5.4 Supporting Equipment

Support equipment common to die casting includes the following:

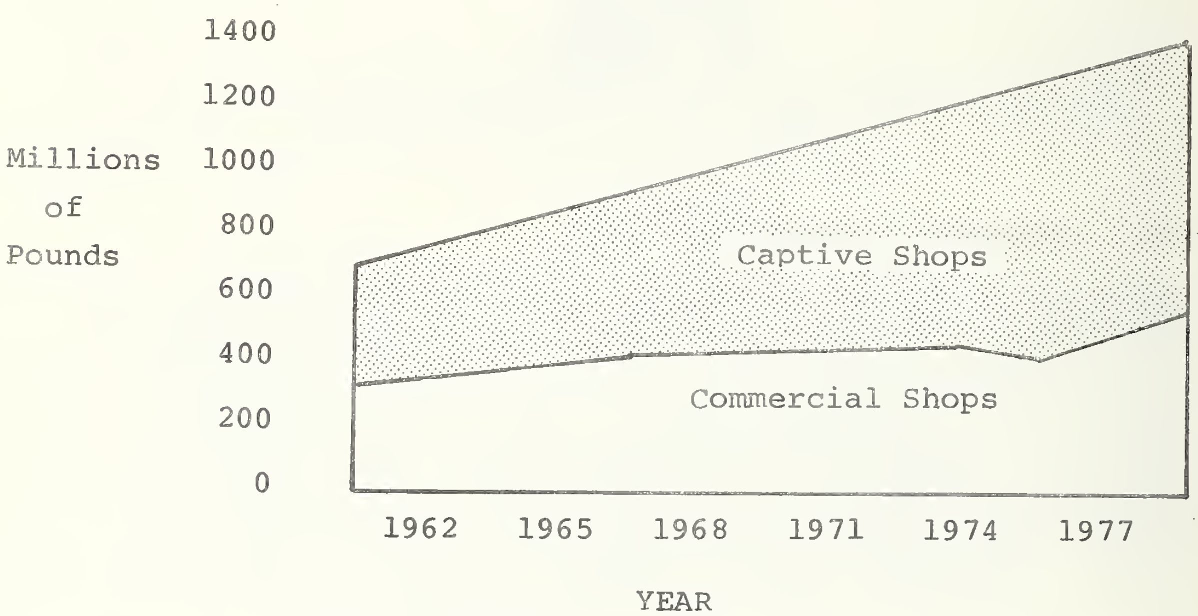
- Fork lift trucks
- Specimen analysis equipment
- Specialized maintenance tools
- Asbestos suits, helmets, gloves
- Conveyors.

Fork lift trucks are integral to the operation of the die casting plant. They lift and transport raw and finished materials, and are used to load final shipments. Fork lift trucks range in price from $20,000 to $60,000 depending upon size. Leading manufacturers are Hyster Corporation, Eaton and International Harvester.

Additional equipment is required for analyzing the soundness of the castings. Spectrometers, compression instruments, moisture detectors, permeability meters, and radiography equipment may be used for this purpose.

6.6 SIZE AND STRUCTURE OF THE INDUSTRY

In 1977 aluminum die casting accounted for 67 percent of all aluminum casting shipments. Die casters tend to be separate from sand or permanent mold foundries. As can be seen in Figure 14, aluminum die casting has had substantial growth in recent years with especially large growth among captive die casters. Aluminum tonnage has more than doubled in 15 years, and captive shops have steadily increased their share of the market, from around 54 percent in 1962 to 64 percent in 1977. Zinc die casting tonnage has remained level in recent years, with approximately 840 million pounds in 1977.



Source: American Metal Market

FIGURE 14
Aluminum Die Casting Shipments, 1962-1977

The predominant die caster is Doehler-Jarvis, which pioneered much technical work in die casting. Many other die casters are derivatives of this company. Outboard Marine is another die caster that has made significant technical contributions to the industry. There are now approximately 1,000 aluminum die casters and 460 zinc die casters in the entire industry, and about half are captive operations. Die casters often do machining and finishing as well as casting.

6.6.1 Commercial Shops

Automobiles are a major market for die castings, counting for 41 percent of aluminum casting tonnage in 1976 and 50 percent of zinc casting tonnage. Approximately 100 commercial aluminum die casting shops supply a major portion of their output to the auto industry. These shops tend to be medium-size facilities employing around 150 people. Doehler-Jarvis is the major aluminum die casting supplier to the auto industry. Others include Dupage, Superior, Heick, Midland Ross, and Hoover Universal. Of the 460 zinc die casters, 44 percent report shipments to the auto industry.

6.6.2 Captive Shops

All the major auto companies have die casting capability except American Motors. Approximately 74 percent of all aluminum automotive die casting was done by captive shops in 1976. The auto companies tend to have large machines (up to 3,000 tons) that can make large automotive parts such as automatic transmission castings. Smaller covers and castings tend to be done by outside shops.

If blocks, heads, and manifolds become die cast parts in the next few years these large parts would very likely be done on the large machines at captive auto shops. This would release smaller castings now done in-house for manufacture by independents. A study released by the Aluminum Die Casting Institute projects that both independent and captive automobile die casting output will be higher by 1980, but that captive shop output will be rising twice as fast as commercial shop output.

6.7 TYPICAL PLANT

The following discussion describes the plant layout, materials flow, capital requirements, labor and energy requirements for a 15,000 ton per year aluminum die casting plant.

6.7.1 Plant Layout

The arrangement of equipment and special working areas in a typical die casting plant are shown in Figure 15. Normally, furnaces and die casting machines are designed around aisles. These aisles are used for transporting of molten metal in fork lift truck-mounted ladles and for the flow of parts. Aisles are approximately eight feet wide.

The overall plant is designed for a well channeled workflow from melting and die casting to trimming and the secondary operations of drilling, milling, turning, tapping and grinding. Final inspection is a logical way station between machining and shipping. Although not visible in the figure, overhead bridge cranes provide handling for heavy machinery and large dies.

6.7.2 Materials Flow

Two types of materials flow through a die casting plant, the basic metal to be cast, and materials to support the equipment operation.

Casting Materials

The material to be cast, such as aluminum, is received at the shipping dock in ingots and then transferred to the melting area where it is loaded into a primary melting furnace. Once melted and metallurgical checks are completed, the molten aluminum is transferred to a holding furnace. From here it is carried in ladles on fork lift trucks or by minirail to the die casting machines and emptied into automatic dispensing units. When the aluminum casting is ejected from the die casting machine, it is taken to an area for trimming and then to secondary machining operations. Finally, the castings are inspected and sent to the shipping area where weighing of filled baskets takes place to ensure that the proper quality is being shipped.

Ancillary Materials

Ancillary flows of materials involve the movement of dies to and from the die room as parts runs are changed. Numerous support equipment is constantly on the move, such as die lubricants, quality control devices and gauges to check equipment.

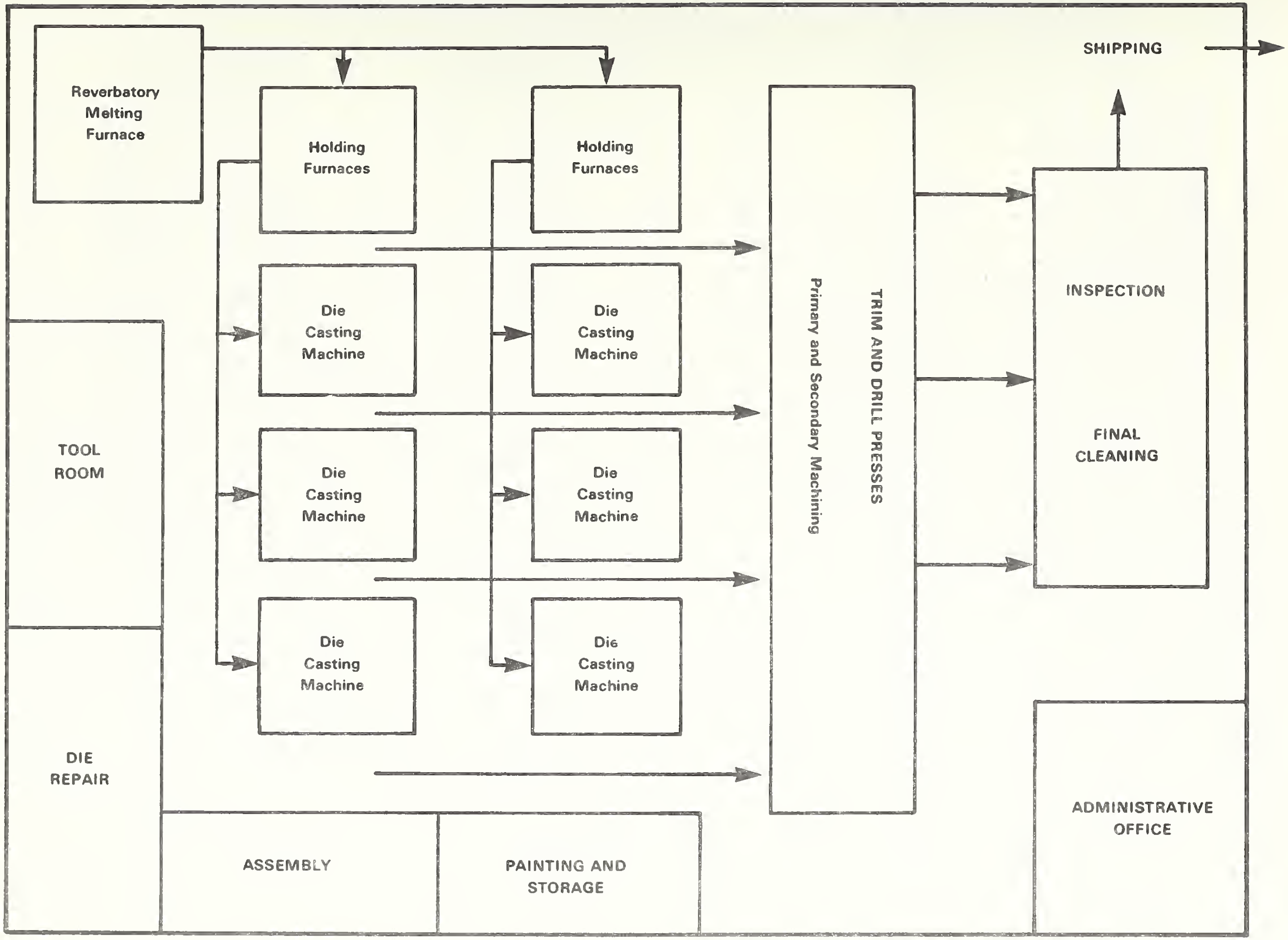


FIGURE 15
Typical Die Casting Plant Layout

6.7.3 Capital Requirements

Capital investment requirements for the plant* are $4.5 million for building and land, and $9.9 million for equipment. The plant is constructed of precast concrete with a poured concrete floor and is located on a 32-acre site. Equipment is the most expensive capital item, principally due to the high cost of dies and die casting machines. Total capital requirements are $21 million.

Building and Land

Basic requirements for the 70,000 square foot die casting plant include the following:

- Precast concrete construction
- Eight inch poured concrete floor
- Steel supported mezzanine over selected areas in the plant
- Twenty-seven foot ceiling in the die casting area
- Complete air, water and electricity hook-ups
- Air conditioned office equivalent to 10 percent of the total plant area with an office ceiling height of 8 feet
- Adequate ventilation and fume control system
- Cafeteria
- Paved parking lot
- Adequate lighting outside the building.

At a price of $50 per square foot total building cost would be approximately $3.5 million.

A 32-acre tract of land would provide plenty of room for employee parking and any future plant expansions. At a minimum, the plant site should provide the following:

- Location within commutable distance of a city with airport facilities
- Industrial zoning

* A hypothetical "typical" plant

- Full utilities (gas, water, electricity, sewage disposal).

The total building and land costs are summarized in Table 3.

TABLE 3
Building and Land Requirements for A
Die Casting Plant

Capital Requirement	Cost $ Millions
Building (70,000 square feet at $50 per square foot)	$3.5
Land (32 acres at $30,000 per acre)	.96
TOTAL	$4.46

Equipment

Equipment requirements for the die casting plant are summarized in Table 4. Principal equipment includes furnaces, die casting machines, dies, trim and drill presses and inspection and testing equipment. Total equipment costs are approximately $9.9 million.

6.7.4 Labor Requirements

Labor requirements are summarized in Table 5. The total of 108 employees includes staffing for two 10-hour shifts with 11 administrative and 97 production workers. Administrative personnel include plant managers, an accountant, sales manager, engineer/quality control supervisor and clerical staff. Production workers include foremen, group leaders, furnace tenders, die setters, die casting machine operators and support personnel.

TABLE 4
Equipment Requirements For A
Typical Die Casting Plant

Equipment	Quantity	Unit Price (Thousands)	Total Price (Thousands)
MELTING:			
Melting Furnace (1,500 pounds per hour)	3	$300	$ 900
Holding Furnace	2	75	150
Automatic Ladles	2	15	30
DIE CASTING:			
Die Casting Machines (600 ton clamping pressure)	10	175	1,750
Dies	20	200	4,000
MACHINING:			
Trim Press (with die)	8	160	1,280
Drill Press	14	50	700
Multi-Station Mill	1	300	300
INSPECTION AND TESTING:			
Pressure Tester	1	100	100
Precision Hardness Tester	1	100	100
Gauges and Fixtures	1	50	50
MISCELLANEOUS:			
Fork lift trucks	4	40	160
Conveyors, ventilation, tools		200	200
TOTAL			$9,940

TABLE 5
Labor Requirements For A Two-Shift
Die Casting Plant

Skill	Number
ADMINISTRATIVE:	
Plant Manager	1
Night Manager	1
Secretary/Receptionist	2
Accountant	1
Accounting Clerks	2
Sales Manager	1
Engineer/Quality Control Supervisor	1
Work Scheduler	1
Janitor	1
PRODUCTION:	
Foremen	4
Group Leaders	6
Furnace Tenders	6
Die Casting Machine Operators	20
Die Setters	2
Press Operators	40
Machinery Repairmen	3
Die Repairmen	2
Inspectors	4
Shipping/Receiving Clerks	4
Fork Lift Operators	6
TOTAL	108

6.7.5 Energy Requirements

Expenditures for energy are approximately 3 to 5 percent of the total die casting production cost, including metal purchase.* Energy costs include oil or gas fuels (if used for furnaces) and the electric power required for operating machines in the foundry, trimming department, tool room and ancillary services.

Metal furnaces are not efficient fuel users. An open flame reverbatory furnace operates at 40 percent of thermal efficiency. Electric resistance furnaces and induction furnaces may operate at 60 to 70 percent efficiency. Heat loss from furnaces may be improved through correct insulation and automatic temperature control.

An efficient furnace would require about 400 kwh per ton to melt aluminum. A planned melting capacity of 1.5 tons per hour would require 800 kw of power. Power requirements for holding furnaces are around 150 kw per ton. The only other significant energy requirement would be plant heating, and this would depend on location.

6.8 KEY ISSUES

Key issues facing die casters include:

- Shortage of skilled workers
- Need for capital expansion
- Expanding use of integrated manufacturing systems.

6.8.1 Shortage of Skilled Workers

The principal labor issue facing die casters is the lack of skilled workers. Many of the older skilled tool and die makers and die casting operators are tied to large companies by seniority and pension benefits. These large companies are becoming very concerned, however, as the average age of their skilled work force rises over 50. Companies have been unable to attract younger people as backup for

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* The Die Casting Book, by Arthur Street, 1977, pages 6-7.

eventual replacement. Small foundries are taxed even more by their inability to match the benefits packages of the large firms in attracting skilled workers.

Automation is a potential solution to the problem but only a partial one. Integrated die casting systems will, by themselves, require additional skilled personnel to handle the systems. A survey conducted by Foundry Management and Technology magazine identified the following major problems of foundrymen:*

- Shortage of skilled labor for all departments
- Shortage of engineering skills in the foundry
- Absenteeism of hourly employees
- Turnover.

6.8.2 Need for Capital Expansion

One of the most difficult problems that die casting foundries are facing is the effect of inflation on needed capital expansions. The die casting industry is capital-intensive, but replacement of worn-out or obsolete machinery or buildings is very difficult in the current inflationary era. Money reserves normally set aside for such purposes are suddenly insufficient. Borrowing money for new facilities is difficult and costly because interest rates are increasing rapidly in the anticipation that they will continue to rise and that loans will be paid back with cheaper dollars. In addition, foundry earnings are taxed at a high rate. This makes it difficult to pay adequate dividends to attract investors or to generate capital out of retained earnings.

The combination of inflation, high taxes and lack of investment reduces replacement or expansion of facilities, leading to obsolescence of equipment, high production costs and ultimately to loss of jobs.

Inflation is forcing foundry managers to become more sophisticated in increasing productivity, cutting costs of material and labor, and increasing utilization of facilities if they intend to stay in business. The challenge to foundry managements is clear, and smaller foundries will be under great pressure to survive.

* Foundry Management and Technology, "What Foundrymen Say," February, 1979.

6.8.3 Expanding Use of Integrated Manufacturing Systems

To spead production and reduce labor costs some die casters are purchasing integrated manufacturing systems. The manufacturing systems unite the separate activities of machines, computers and the die casting operator. A network of machinery can perform casting, guenching and trimming operations while virtually eliminating the need for individual machine operators. With the support of specially designed robots, the die casting operator is freed to carry on inspection activities.

This expansion in integrated and computerized manufacturing is boosting the sales of automatic equipment suppliers. Manufacturers which are experiencing increased orders from die casting shops include makers of:

- Automatic ladles
- Automatic extractors (robots)
- Automatic die casting machines
- Automatic die spraying devices
- Automated scrap collecting systems.

The significance of this trend is that die casters are fast seeking solutions to their labor shortage and productivity problems through automation.

The use of computers in die casting shops is expected to grow. Small process controllers located in the foundry may, in the future, be tied in with large, more powerful, high storage capacity central system computers. These will provide interactive, real-time controls and will compute and control processes for optimal results with a minimum need for human intervention.

7. AUTOMOTIVE FORGING PROCESSES

7.1 GENERAL

Forging is the process of applying pressure to metal to shape it. The metal undergoing deformation must be in compression during the process. This distinguishes forging from other shaping processes such as drawing or stamping which are achieved by tensile forces. Traditionally, forging involved heating a metal prior to shaping. Currently, however, forging is performed both hot and cold.

Forging is used for manufacturing many automotive parts such as connecting rods, ball joints, differential spiders, tie rods and stabilizer bars. In general, forgings are more expensive than cast parts. However, they are more appropriate for highly stressed components due to enhanced mechanical properties that result from:

- Consolidation of internal voids
- Flow patterns of the crystal grains
- Uniformity of grain size
- Better response to quench and temper heat treatment (hot forging only)
- Work hardening (cold forging only).

The automotive industry is very important to the independent forging industry and accounts for about 26 percent of non-captive company sales.

7.2 STEPS IN THE FORGING PROCESS

As in the casting industry, forging industry processes are quite varied but have some common operations as illustrated in Figure 1. Forging starts with metal in the form of billets, bars, and rods which must be sized to provide a proper volume of metal for forging. Cold forging requires stock to be softened (annealed structure) and lubricated prior to compression. Hot forging requires even softer metal (heated to high temperatures) for compression.

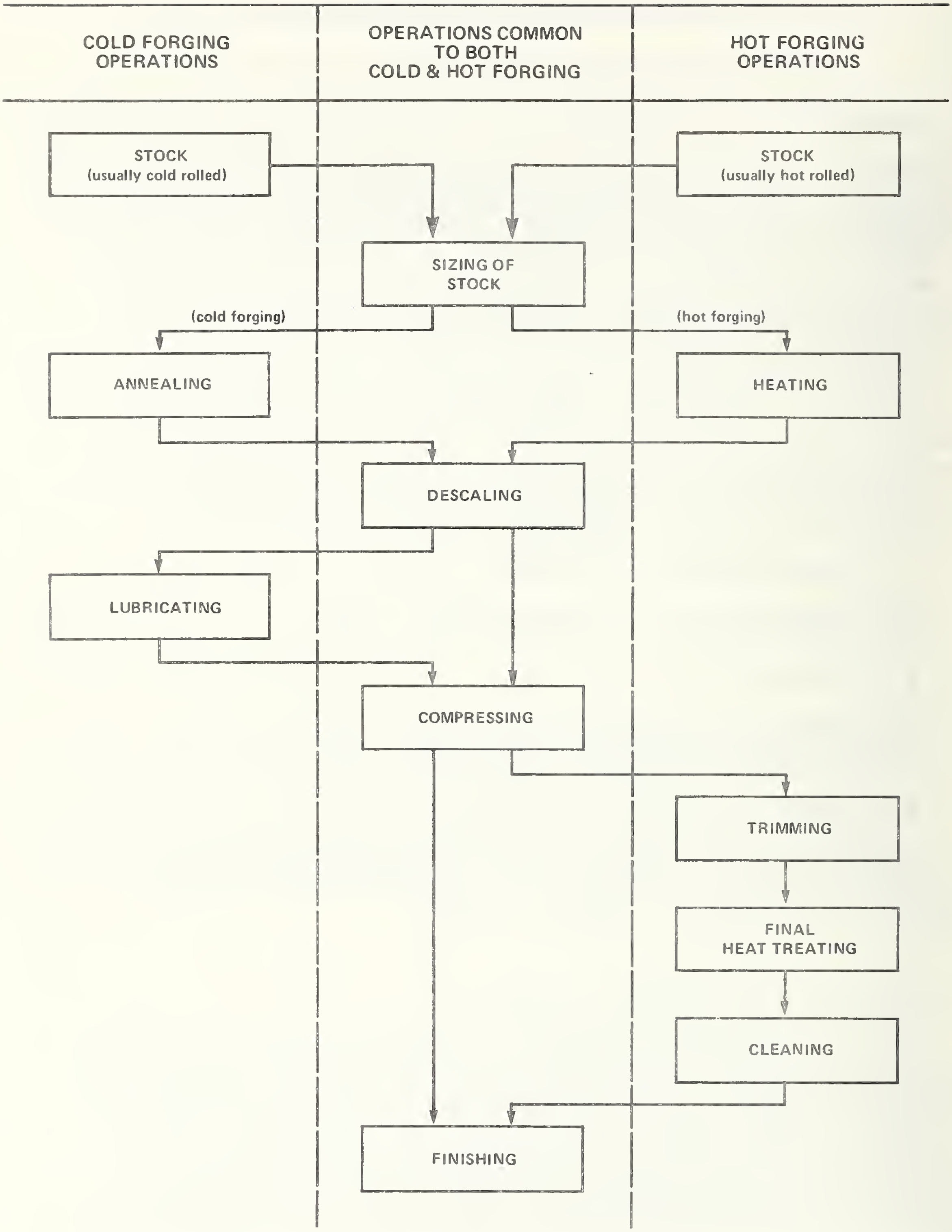


FIGURE 1
Overview of Forging Operations

Both operations demand that the material be free of scale before it is shaped (compressed).

Cold forging requires more force to shape parts primarily because the metal is cold. Some of the tremendous energy required for cold forging is stored in the metal, and this stored energy makes the metal harder and stronger. When metal is forged hot, less energy is required and no energy is stored. If increased strength or hardness is required, the part must be heat treated for these properties.

Cold forging yields a product which requires no further operations to alter its size or finish. Conversely, hot forging inherently creates considerable amounts of scrap through trimming off excess metal. Machining and/or coining (finishing steps) are used if the hot forged part needs a finish equivalent to that of a cold forged part. Finishing steps for cold forged parts are minor and consist mostly of cleaning off adherent lubricant and zinc phosphate if subsequent surface coatings are desired.

7.3 OVERVIEW OF FORGING PROCESSES

Cold forging is a much newer and smaller contributor to the auto industry than hot forging, but it has established itself as an important branch of metalworking. The basic processes covered in this report are defined as follows:

- Hot Forging. Hot forging is defined as the forging of any metal above the recrystallization temperature. Many metals can be hot forged, but for reasons of costs and mechanical properties, only hot forged steel parts are used in the automobile. Steels are hot forged in the temperature range of 2150-2350 F, well above the recrystallization temperature (1000-1200 F). The reason for this is that steel has a much more malleable crystal structure at the higher temperatures.

- Cold Forging. Cold forging is defined as the shaping by compressive force of any metal below its recrystallization temperature. The recrystallization temperature is that temperature to which the metal must be heated for energy stored in the metal by cold working to be released and for new crystalline grains to form. With the formation of new grains, the original annealed mechanical properties are restored in the metal.

8. HOT FORGING

8.1 GENERAL

Hot forging is the process of shaping a heated metal workpiece between dies by hammering, pressing, rolling or upsetting. The operation serves the dual purpose of shaping the material and enhancing its mechanical properties. The intricacy of the dies determines whether the resultant forging is a finished or semi-finished product. Finished products need only to be heat treated, cleaned and occasionally ground before shipment. Semi-finished products will be transferred to another forging operation or subjected to substantial machining prior to heat treatment and finishing operations. Automotive parts which are hot forged include connecting rods, steering idler levers, tie rods, and crankshafts.

8.2 MAJOR TYPES OF HOT FORGING

The major types of hot forging are categorized by the types of dies and the types of metals used.

8.2.1 Types of Dies

The major types of dies in hot forging are:

- Open die
- Roll
- Impression die
- Upset.

Open die forging utilizes crudely shaped dies; thus its products need considerable subsequent processing. This method of forging is not suitable for high volume production and is not used in the manufacturing of automotive parts. Roll forging is primarily used to pre-shape a workpiece which will be transferred to an impression die hammer or press forging operation; however, in some cases a workpiece is sent through several sets of rolls to yield a finished product. Impression die and upset forging operations are capable of producing relatively close tolerance parts which undergo very little subsequent processing. These two types (i.e., impression die and upset forging) are the cardinal hot forging operations used for manufacturing automobile parts.

Open Die Forging

Open die forging is the compressing of a metal workpiece, usually an ingot or billet, between dies which impinge upon the piece tangentially and restrict the flow of metal in only one dimension. This forging technique is used to make low production run items having relatively little detail and weighing as little as a few pounds or as much as 300 tons. Shapes commonly made between open dies include rounds, squares, rectangles, hexagons, octagons and simple pancakes. These shapes are intermediate products for end products such as spindles, pinion gears, rotor forgings, ship shafts, bucket wheels and tube sheets.

Figure 1 shows four types of die sets most commonly used in open die forging. A description of the four die sets shown in Figure 1 is as follows:

- Flat Dies. These dies are used in the initial pass on an ingot to quickly reduce the cross-section of the piece, consolidate interval voids in the material and break up large columnar grains which are formed during the cooling of the ingot. Flat dies are also used to make simple pancakes from cylinders which have been stood on end.

- V-Dies and Flat/V-Die Combinations. Die sets comprised of one flat die and one V-die or two V-dies are used for transforming an octagon cross-section into a round cross-section.

- Swaging Dies. Swaging dies are used to reduce the diameter of a round cross-section piece.

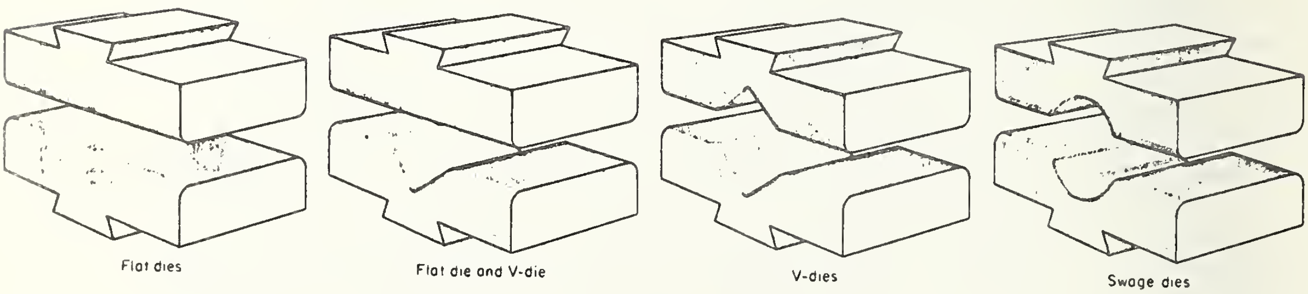


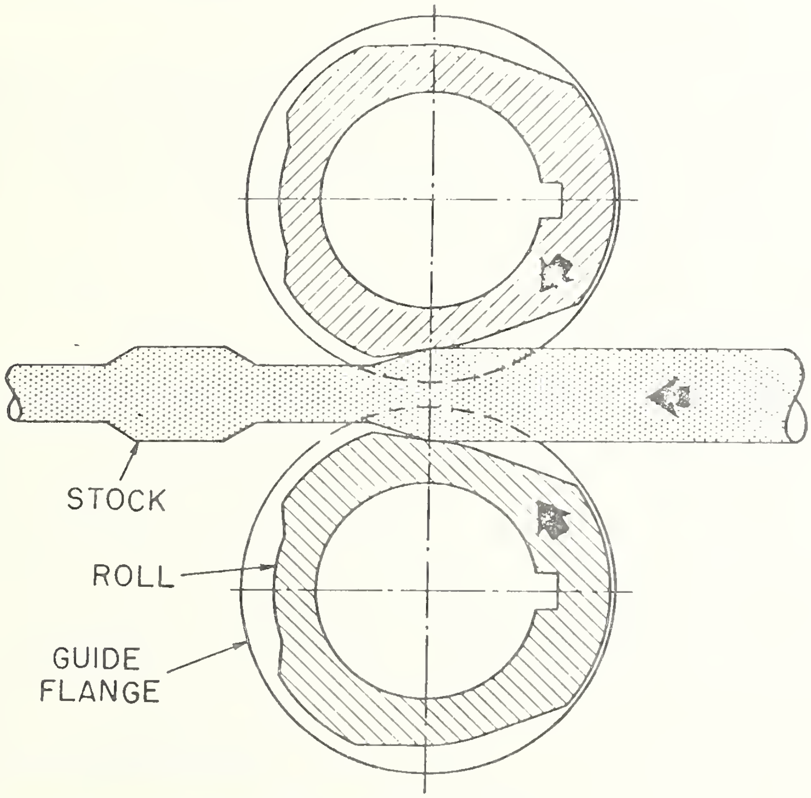
FIGURE 1
Four Types of Die Sets Commonly Used in Open-Die Forging

Open die forging is not suitable for high volume production and therefore not applied to the production of automobile parts. Characteristics of the operation which make it undesirable for automotive applications include:

- The cycle times are slow.
- Extensive machining is required after forging.
- The operation is highly labor intensive.

Roll Forging

Roll forging is the shaping of metal, usually in the form of sectioned bar stock, between a pair of rolls. A diagram illustrating the roll forging operation is presented in Figure 2. It can be seen that roll forging differs from rolling mill operations in that the cross-section of the product varies along its length. During the roll forging operations, a piece is sent through the same set of rolls at least twice, with the workpiece being rotated 90° before each additional pass.



Source: Forging Industry Handbook, 1970

FIGURE 2

Roll Forging Operation

Roll forging is predominantly used as a preliminary operation prior to impression die or upset forging; however, it can also be used as the sole forging operation. As a preliminary operation, its functions are to:

- Reduce the cross-section and elongate the workpiece at various locations along its length (i.e, pre-shaping)
- Break off scale formed during heating prior to forging (i.e., descaling).

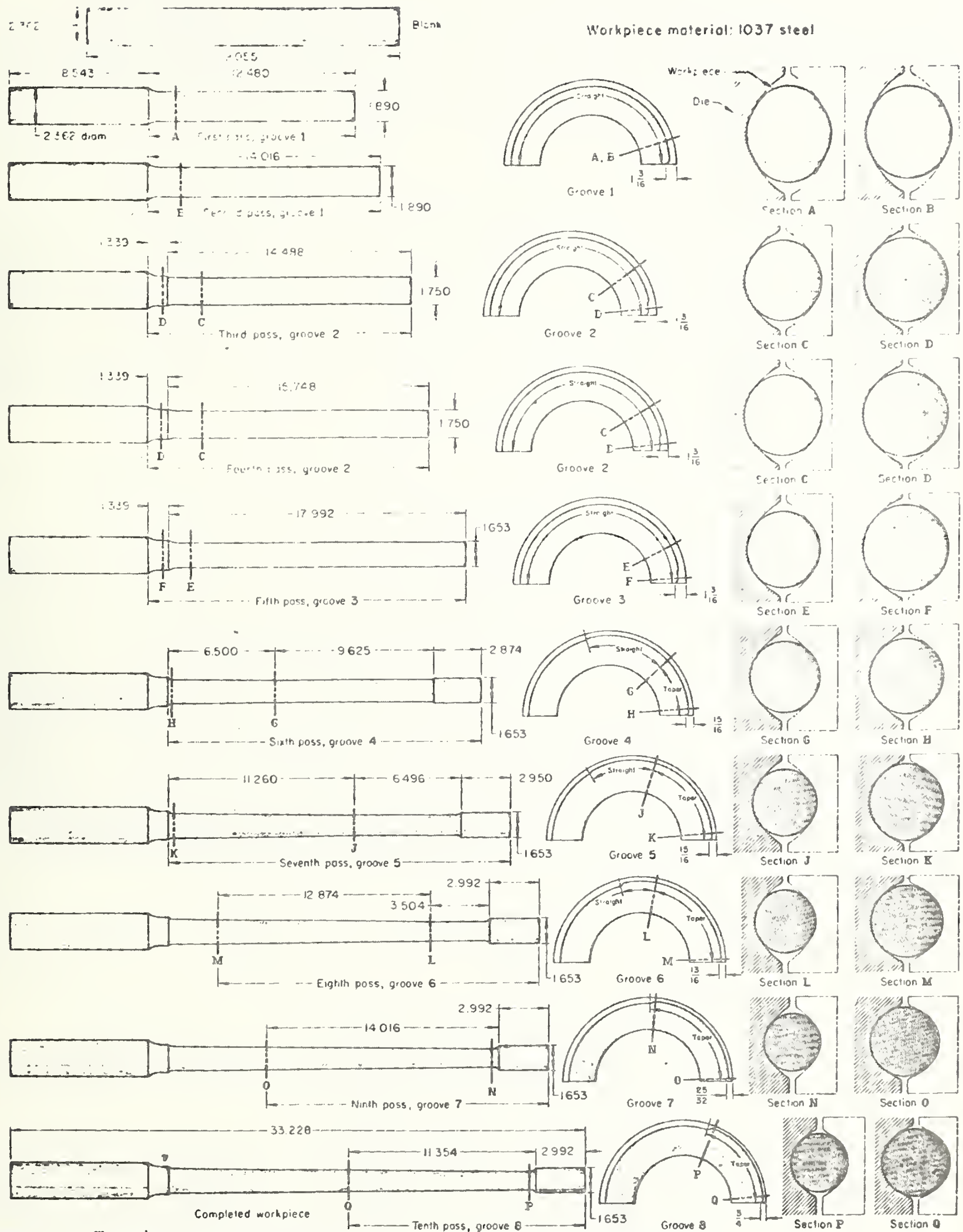
Pre-shaping acts to save material and reduce cycle times of subsequent impression die forging. This is true because less flash is created, and the number of cavities needed in the die block are reduced when the metal has been gathered to where it is most needed prior to impression die forging. Descaling by roll forging is important as a preliminary step to press forging because that operation tends to embed the scale into the hot metal rather than break it off. The descaling function of roll forging is less critical prior to hammer forging because the impact loading of that process tends to break the scale away from the surface.

Although the predominant application of roll forging is pre-shaping, some parts such as axle shafts can be made by roll forging. Figure 3 shows the steps in making an axle shaft in ten passes. The large diameter at the right end of the part was made in an upsetter.

Impression Die Forging

Impression die forging is the shaping of hot metal completely within the cavities of two dies that come together to enclose the workpiece on all sides. This process is capable of producing a high volume of complex parts that require a minimal amount of subsequent machining and which range in size from a few ounces to several tons. Although 70 percent of all impression die forgings weigh two pounds or less, steel forgings weighing as much as 33,000 pounds and with maximum dimensions of 35 inches wide by 115 inches long have been successfully forged.

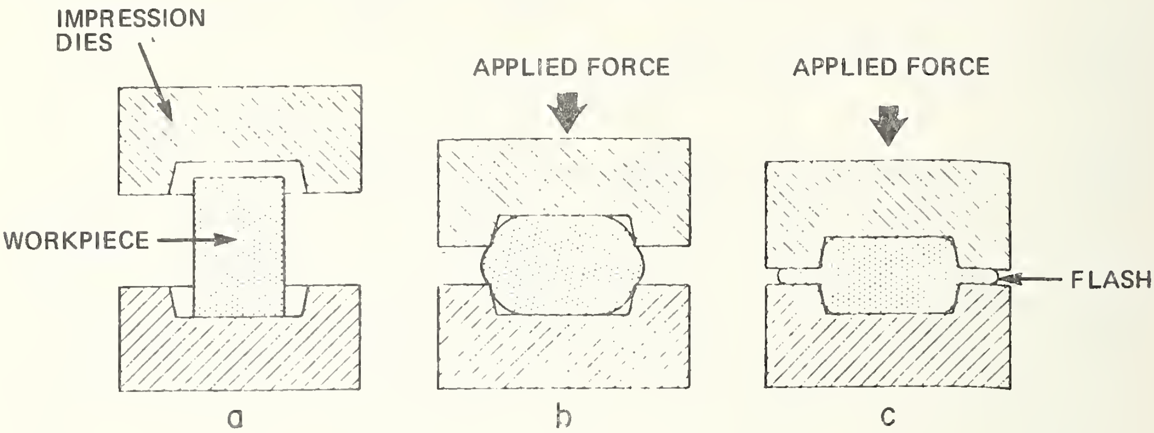
The diagram in Figure 4 formats the general concept of impression die forging. Stock is placed between two dies which are forced together by action of a hammer or press. Under the influence of compressive forces, the metal flows in the direction of least resistance, thus causing the hot metal to fill the cavity. That metal



Source: Forging and Casting, Volume 5 of The Metals Handbook

FIGURE 3
Forging an Axle Shaft in Ten Passes Through Eight-Groove Semicylindrical Roll Dies

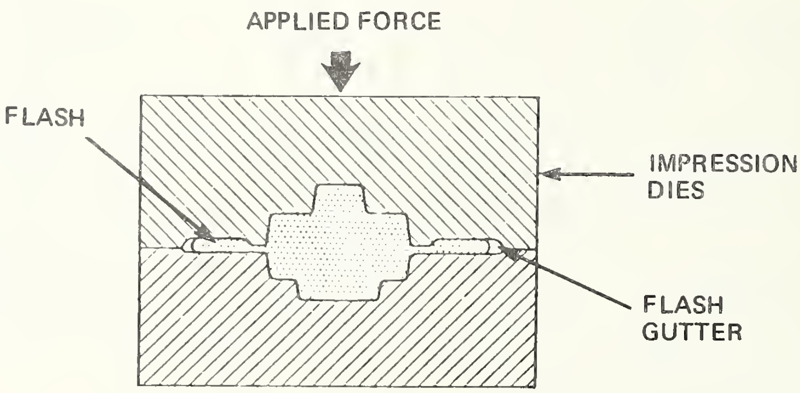
which is forced out between the two dies, called flash, must be subsequently removed. During forging, the flash acts as a relief valve for extreme pressures exerted on the workpiece. Once the flash has formed, it acts as a die sealant which prevents further escape of metal and forces the workpiece to fill the die cavities.



Source: Forging Industry Handbook, 1970

FIGURE 4
Compression in Simple Impression Dies Without Special Provision for Flash Formation

Because the flash is relatively thin, it cools rapidly by heat conduction through the die surfaces. Metal is more deformation resistant when it cools, and, being less plastic, flash can reduce die life. For this reason, flash gutters depicted in Figure 5 are sometimes designed into the die to reduce the pressure exerted on the die faces.



Source: Forging Industry Handbook, 1970

FIGURE 5
Impression Die Having Flash Gutter

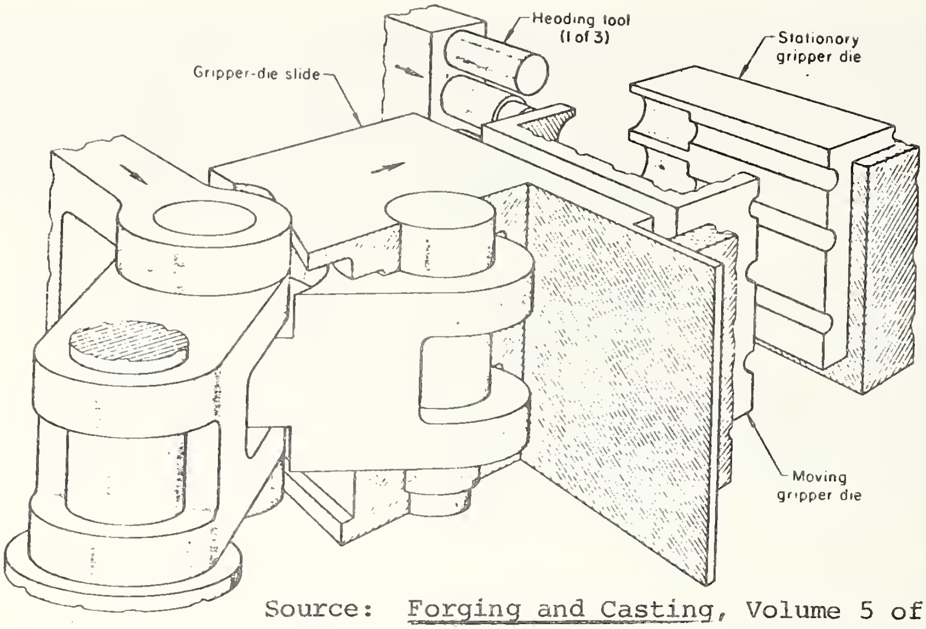
Another method for reducing the pressures that reduce die life is closed die forging, in which no flash is formed. This type of forging poses additional design requirements, however. Vents must be built into the dies to release pressure buildup of trapped gas and lubricant. Also, the stock must be sized with extreme accuracy so that the die cavity is completely filled yet no metal remains for flash formation.

True closed die forging (flashless forging) is a special sub-category of impression die forging. It has limited commercial use and is totally absent in the manufacturing of automobile parts. As a point of clarification, the term closed die forging is often used in industry when impression die forging, which involves flash formation, is the technically correct terminology.

Upset Forging

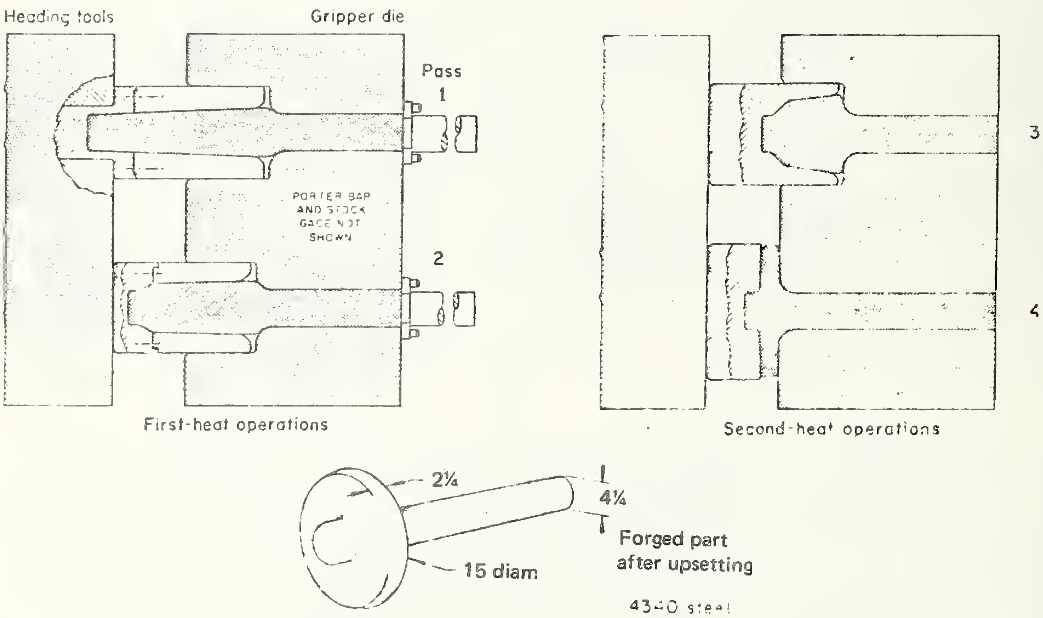
Upset forging is the enlarging or reshaping of some of the cross-sectional area of a bar, tube or other product by applying a compressive force along the longitudinal axis of the workpiece. In its simplest form, upset forging involves the striking of one end of a bar with a forming die called a header while the other end of the die is held between two gripper dies, one of which is a stationary die and the other is a movable die. During the upset forging cycle, the movable die slides against the stationary die to grip the stock. (See Figure 6.) The header tool fastened in the header slide advances toward and against the forging stock to spread it into the die cavity. When the header tool retracts to its back position, the movable die slides to the open position to release the forging. This permits the operator to place the partly forged piece into the next station, where the cycle of the movable die and header tool is repeated.

Variations of upset forging exist in which one end or the entire stock is heated prior to forging and in which one end or both are reshaped. The same forming tools used for upsetting can also be used for punching, internal displacement, extrusion, trimming and bending. Many forgings can be produced to final shape in a single pass of the machine. Others may require as many as five passes for completion. Figure 7 shows the hot upsetting of a piece of stock into a flange by a process sequence of heating, two upset passes, heating, and two more upset passes. The shape is representative of the type of work done in producing automotive parts.



Source: Forging and Casting, Volume 5 of The Metals Handbook

FIGURE 6
Basic Actions of the Gripper Dies and Heading Tools of an Upsetter



Source: Forging and Casting, Volume 5 of The Metals Handbook

FIGURE 7
Tooling Setup for Upsetting a Flange in Two Heatings and Four Passes

A clarification of forging nomenclature should be made. In forging terminology, the process of upsetting is any forging conducted with the compressive force parallel to the longitudinal axis of the workpiece resulting in shortening of the piece and the increasing of its diameter. An upsetting action can be achieved by open die forging, impression die forging and by a separate major type of forging just discussed and commonly referred to by four names: upset forging, hot heading, hot upsetting or machining forging. When reading forging literature, it is necessary to infer from context whether the part was forged in hot upset forging equipment or whether the workpiece was compressed axially during open die or impression die forging.

8.2.2 Metals Used

The forgeability of a metal or alloy is its tolerance for deformation without failure. In general, this property is enhanced with increasing temperature until a temperature is reached which cannot be exceeded without detriment because either a second crystalline phase appears, melting begins, or, in some instances, grain growth is excessive. The minimum temperature at which a metal is technically hot worked is its recrystallization temperature. The recrystallization temperature for several materials is shown below in Table 1.

TABLE 1
Recrystallization Temperatures

Material	Temperature
Lead	25°F
Tin	25°F
Zinc	50°F
Copper (Commerical)	400°F
Copper Alloys	550-700°F
Aluminum (99.0%)	550°F
Aluminum Alloys	600°F
Magnesium Alloys	450°F
Low Carbon Steel	1,000°F

In addition to temperature, factors influencing forgeability include composition, purity, number of phases present, grain size, strain rate, stress distribution and crystal structure.

Table 2 presents a ranking of forgeability of materials in order of decreasing forgeability. Lead, tin, and zinc are not included because their recrystallization temperature is so low, and because they are so malleable at room temperature, that hot forging is not necessary.

TABLE 2
Forgeability of Materials

Aluminum alloys
Magnesium alloys
Copper alloys
Carbon and alloy steels
Martensitic stainless steels
Maraging steels
Austenitic stainless steels
Nickel alloys
Semi-austenitic PH stainless steels *
Titanium alloys
Iron-base super alloys
Cobalt-base super alloys
Columbium alloys
Tantalum alloys
Molybdenum steels
Nickel-base super alloys
Tungsten alloys
Beryllium

Metals commonly used in the automobile, aluminum, carbon steels, and engineering alloy steels, are all easily hot forged. Wrought aluminum parts in the automobile are not hot forged, however, because they are so easily cold forged. Magnesium alloys, candidates for future automotive parts, will more likely be cold forged than hot forged for that same reason. Metals in the cast iron group, namely gray iron, malleable iron and ductile iron, cannot be forged because their crystal structure gives them very poor malleability even at elevated temperatures.

* PH = precipitation hardening.

8.3 ADVANTAGES AND DISADVANTAGES OF HOT FORGING

Hot forging has several advantages over casting including better mechanical properties such as the following:

- Yield strength
- Ultimate tensile strength
- Ductility
- Impact strength
- Fatigue resistance.

These enhanced properties are attributable to consolidation of pores in the metal, and grains which are uniform in size and are oriented in a flow pattern that resists bending stresses. Also, the smaller grains of forgings allow better response to quench and temper heat treatment. All of the above factors add up to high strength to weight ratios, which are important for weight savings in automobiles.

Forgings can also be made to closer dimensional tolerance and smoother finishes than castings. The dimensional characteristics are also more consistent from one piece to the next because there is no positive-to-negative-to-positive transfer required. Uniformity from part to part becomes more essential as machining operations become more automated and less supervised. Uniformity of structure is important for the same reason. Because castings are susceptible to surface non-metallics and subsurface porosity which can snag a machining tool and break it, they are less compatible with automatic machining.

Hot forging has one primary disadvantage as compared to casting. This disadvantage is cost. Forging is more costly because it is a much more capital intensive manufacturing process and requires very high production rates in order for the cost of a forging to approach the cost of a casting. In terms of manufacturing limitations, casting is superior for making hollow one-piece parts with complex cavities. This type of part, however, is not found on the automobile. Casting is also superior for making one-piece parts having a highly irregular topography such as cooling fins on motorcycle engines.

Cold forging is preferred over hot forging as a general rule, because of the resultant close tolerances possible without subsequent machining. However, hot forging must be used instead of cold forging for:

- Shaping metals having limited room temperature malleability

- Forging thick sections

- Achieving significant amounts of deformation
- Producing highly non-symmetric parts.

8.4 AUTOMOTIVE APPLICATIONS OF HOT FORGINGS

Automobile parts made from forgings generally require better tensile strength, toughness, fatigue resistance or hardness properties compared with other automobile parts. In most instances, these are the load-bearing components of the car. Structural components which are not forged, such as the frame, are made from rolled products which have a wrought structure similar to that of forgings. The following sections describe the automotive parts made by impression die and hot upset forging, the primary hot forging techniques used in the automotive industry.

8.4.1 Impression Die Forging

Impression die forging is used when the stock must undergo significant deformation to become a final product. Hammers are used for less intricate parts and for parts with thin sections. In the future, as the trend from hammers to presses continues, some parts will be made by hammer by one manufacturer and by press by another. The chief reason will probably be based on which company can afford the capital equipment sooner. Some of the parts presently made by hammer and/or press impression die forging are shown in Figure 8.

8.4.2 Upset Forging

Upset forging is used when the final product does not significantly differ in appearance from a mill product such as a round bar, hexagonal bar or a tube. Upsetting is used to place a flange on one or both ends, or to change the diameter of the bar over some section. For this type of work, the upsetter has replaced an expansive lathing operation. Parts made by hot upsetting are shown in Figure 9.

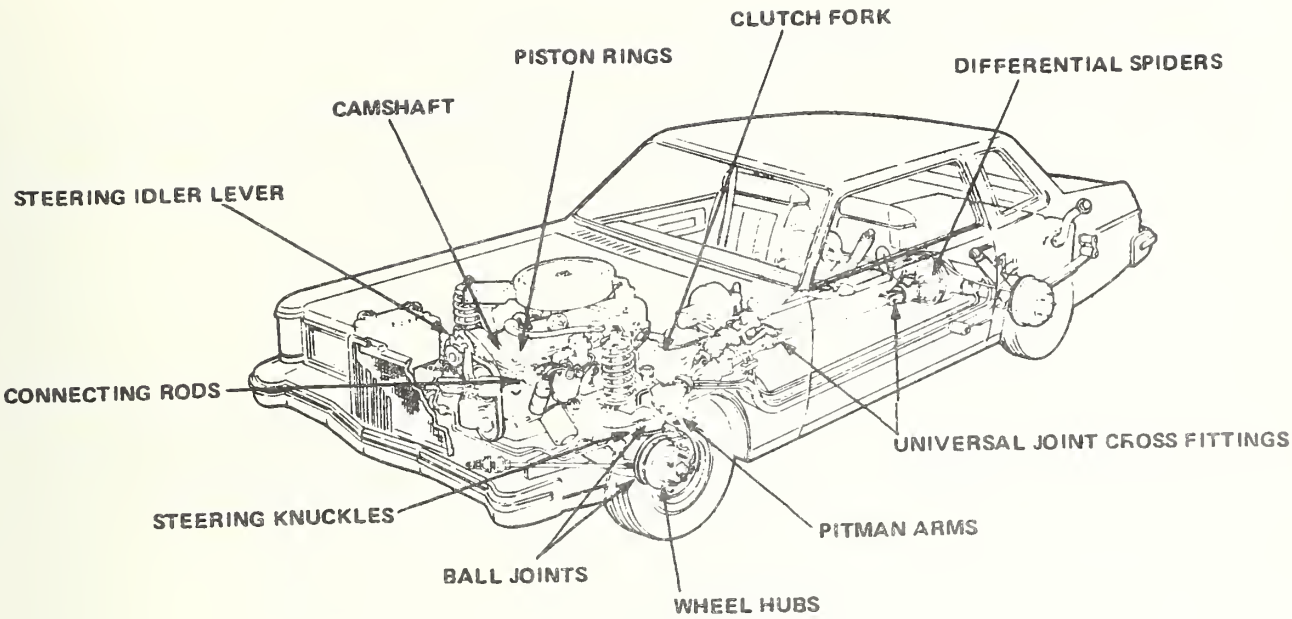


FIGURE 8
Impression Die Forged
Automobile Components

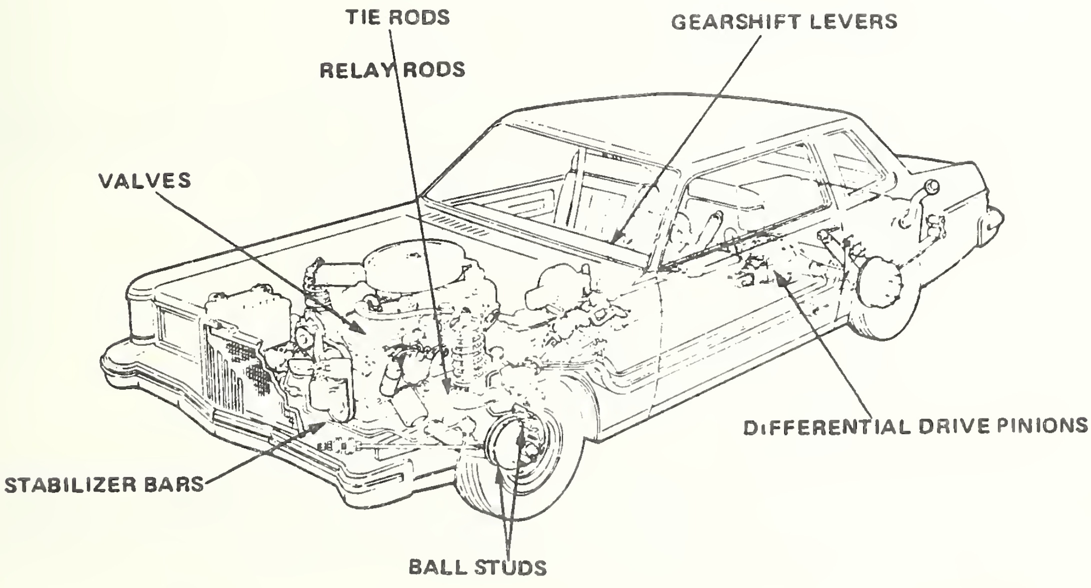


FIGURE 9
Hot Upset Forged
Automobile Components

8.5 EQUIPMENT REQUIRED

Principal equipment required to manufacture hot forgings includes the following:*

- Forging furnaces
- Hammers
- Forging presses
- Upsetters
- Rolls
- Support equipment.

An additional type of equipment which is increasing in popularity but not required is automatic forging equipment.

Each of these is described below.

8.5.1 Forging Furnaces

The range of furnaces available for use in forging plants is myriad. Figure 10 summarizes all of the types of furnaces by:

- Charging procedure
- Furnace design
- Heating process.

The furnace types which are shaded in the figure are those which are most commonly found in forging plants which manufacture automotive components. These include:

- Slot furnaces (direct fuel fired)
- Rotary hearths (direct fuel fired)
- Induction heating furnaces (both pusher and screw furnace designs).

Definitions of each type of furnace along with reasons why they are selected are described below. Capacity, cycle time and price information on selected furnaces are provided in Table 3.

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* Dies would also be needed. Die cost is a function of die complexity and size. For example, a 24" x 24" x 12" die block cut with an impression for making connecting rods would cost approximately $5,000. The life of dies ranges from 20,000 to 50,000 parts produced.

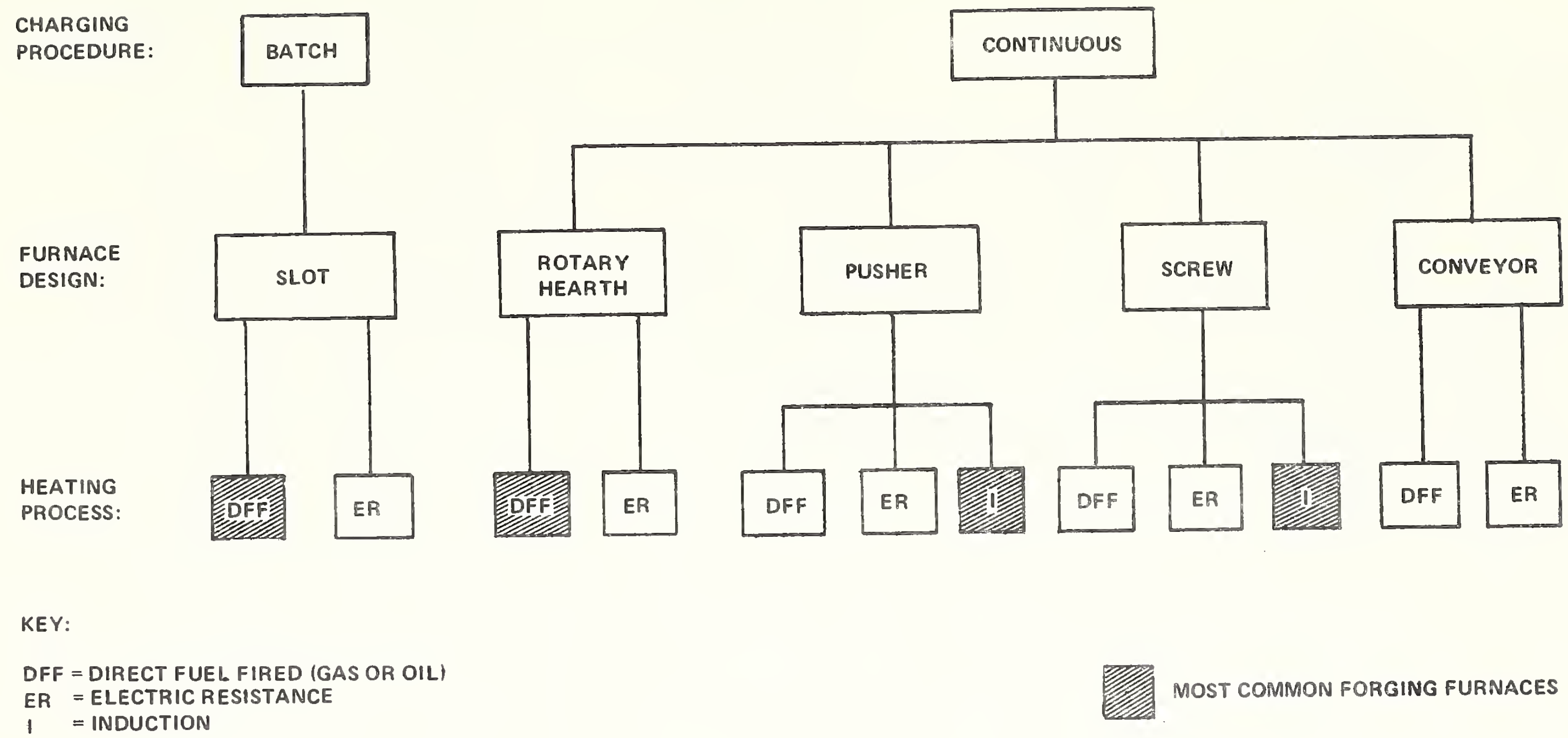


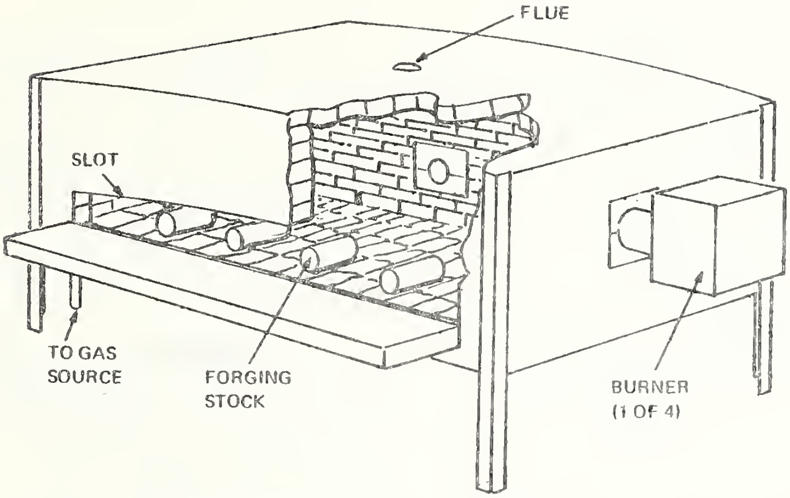
FIGURE 10
Organization of Forging Furnaces

TABLE 3
Forging Furnaces

Equipment	Manufacturers	Capacity	Cycle Time	Lead Time	Price
Fuel Fired Furnaces	Selas American Corp., Lindberg, Surface Combustion, Sunbeam, Ipsen	Examples of slot fces: 1. 4 ft.-manual 2. 20-30 ft.- 3. manual 3. 20-30 ft.-automatic	Dependent on size of stock being heated	5 to 7 months	1. $10,000 2. $80,000 to $100,000 3.$120,000 to $160,000
Rotary Hearth	Selas American Corp., Lindberg Surface Combustion, Sunbeam, Ipsen	1,800 pounds per hour	Dependent on size of stock being heated	5 to 7 months	$65,000
Induction Heating	Westinghouse, Ajax Magnethermic Heating, Tocco, American Induction Heating, Inductotherm, Cheston	Virtually no limit to throughput tonnage. Even 30,000 pounds per hr. units in use.	Example: 1 1/4 in. stock heats in 48 seconds	8 to 9 months	$100,000 to $1,000,000 plus 10% to 20% for installation

Slot Furnace

Slot furnaces are a common batch type furnace where stock is charged and removed through a slot or opening as shown in Figure 11. Slot furnaces are frequently found in small forge shops because they are comparatively inexpensive. They have no moving parts and can accept extreme weight. The direct fuel-fired slot furnace is preferred over the electric resistance type because it requires less initial capital investment. In many instances, it is less expensive to operate and also more energy-efficient.



Source: Forging and Casting , Volume 5 of The Metals Handbook

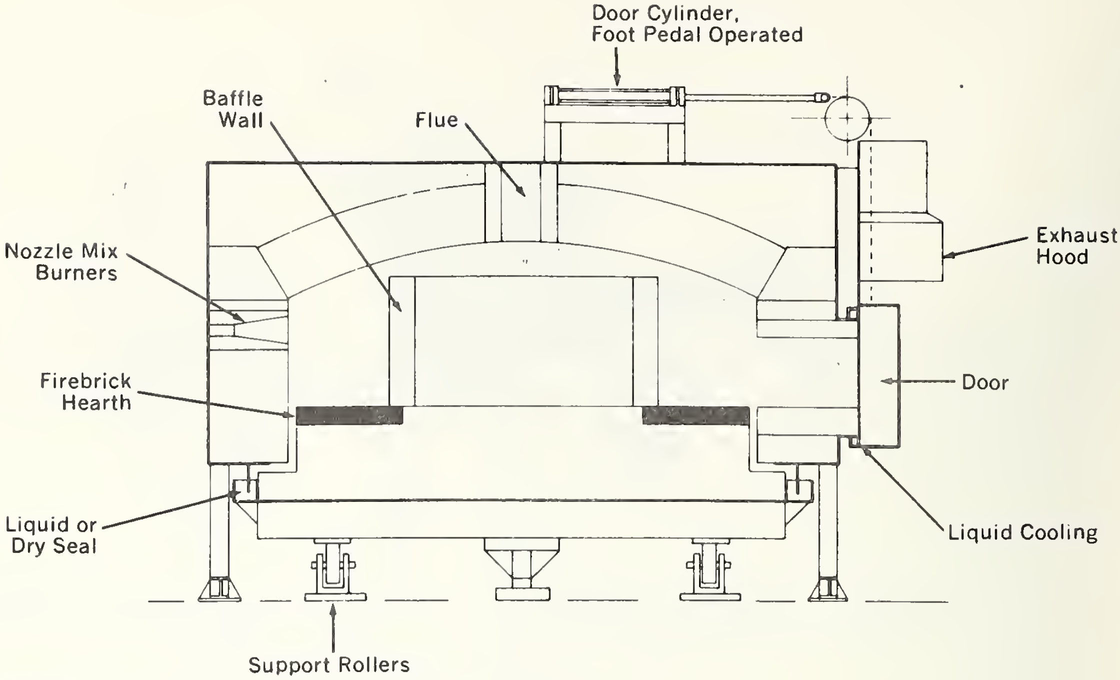
FIGURE 11
Slot Furnace

Direct fuel fired slot furnaces can be built to practically any desired size. The normal range of lengths is from 4 to 10 feet using a single arched roof and from 16 to 30 feet using a double arched roof. They are usually built on a steel frame and have a refractory hearth and firebrick sidewalls and roof. The oil or gas fired burners, located in the side walls, will heat 50 to 100 pounds of steel per hour per square foot of hearth.

The major manufacturers of slot furnaces are Selas American, Lindberg, Surface Combustion, Sunbeam and Ipsen. A typical 4 foot, manually operated slot furnace costs about $10,000; whereas, those in the 20 to 30 foot range cost $80,000 to $100,000. Energy requirements are 3 million Btu per ton of steel.

Rotary Hearth

The rotary hearth is a circular furnace which is constructed so that the hearth and workpieces rotate around the furnace's axis during heating. Material is charged and removed from the same location. Figure 12 shows a typical rotary hearth forging furnace.



Source: Sunbeam Equipment Corporation

FIGURE 12
Rotary Hearth

The principal advantage of the rotary hearth, and the reason for its popularity, is that only one operator is needed to load and unload in cases where the furnace does not have automatic material handling. Direct fuel-fired rotary hearths are preferred over electric resistance for the same cost and efficiency reasons as those cited for slot furnaces.

A typical rotary hearth furnace of average size has a 7 1/2-foot outside diameter with an 18-inch wide silicon carbide hearth for wear resistance. The charging and unloading door measures 18 inches wide by 12 inches high. A direct fuel fired rotary furnace of this size can heat 1,800 pounds per hour at 2300°F and costs $65,000. Major manufacturers are: Selas American, Lindberg, Surface Combustion, Sunbeam, and Ipsen.

Induction Furnaces

Induction heating for furnaces has experienced considerable acceptance as a rapid, relatively scale-free method of heating stock uniformly. As shown in Figure 10, induction heating is available in two continuous furnace designs:

- Pusher furnaces. Stock to be heated is charged at one end, forced through one or more heating zones and discharged at the opposite end. A hydraulic, mechanical or air-operated pusher advances the material.

- Screw furnaces. Similar to pusher furnaces with the exception that the material is advanced by means of a large spiraling screw.

Induction heating is accomplished by passing high frequency alternating electric current through a water-cooled coil surrounding the bar stock. Energy is transferred from the coil to the bar by induction and heating results from hysteresis and eddy current losses within the bar stock. Frequencies generally used for forging purposes are 960 to 9,600 cycles.

Induction furnaces will heat the stock to forging temperature more quickly than fuel-fired furnaces. Other advantages of induction heating are:

- It adapts well to automated operations.

- It provides better working conditions: cleaner, less noise, and less heat thrown off to work area.

- It provides high efficiency per pound of steel heated.

- The equipment is compact.

Some disadvantages of induction furnaces are:

- There is high capital investment compared with fuel-fired furnaces.

- Cost of electricity may be higher than the cost of fuel.

The major manufacturers of induction furnaces are Westinghouse, Ajax Magnethermic, Tocco, American Induction, Inductotherm, and Cheston. The equipment is so fast that there is virtually no limit to production capacity. Units processing 30,000 pounds per hour are in use. Typical units range in price from $100,000 to $1,000,000 plus 10 to 20 percent extra for installation.

8.5.2 Hammers

Forging hammers used in the manufacture of automotive components are of three principal types:

- Board drop
- Air lift-gravity drop
- Power drop.

All three have a weighted ram which, when it moves in a downward stroke, exerts force against a stationary component of the anvil near the base of the hammer. The upper half of a pair of impression dies is fastened to the weighted ram, and the lower half to the anvil cap. The high impact of the joining die halves forces the heated work metal to deform with each successive blow.

Counterblow and horizontal impacter equipment is used instead of drop hammers in some industries to minimize the damage caused by the large hammer impact forces. Counter blow and horizontal impacter equipment is seldom used to manufacture automotive parts.

Prices, lead times and principal manufacturers of forging hammers are summarized in Table 4. Each of the three types of drop hammers is discussed below.

TABLE 4
Forging Hammers

Equipment	Manufacturers	Capacity	Cycle Time	Lead Time	Price
Gravity Drop Hammers - Board, Air and Steam Lift	Chambersburg, Erie	Sizes used in auto part production: 2,000 - 6,000 pounds	Approximately 2 or 3 parts per minute	12 months	$60,000 to $145,000
Power Drop Hammers	Chambersburg, Erie	Examples: 1. 3,000 lbs. 2. 6,000 lbs. 3. 20,000 lbs.	Approximately 3 parts per minute	12 months	1.$200,000 2.$275,000 3.$750,000

Board Drop and Air Lift-Gravity Drop Hammers

Board drop hammers are used for producing forgings weighing no more than a few pounds. To forge a part, the heated workpiece is placed over the cavity of the lower die and the operator depresses a foot treadle which releases the board clamp causing the ram with the top die to fall. After striking the metal, the ram returns to the raised position by the action of one or two motors driving two friction rolls which clasp one or more boards keyed to the ram. In the production of small, simple impression die forgings, the operator causes successive blows to be struck by keeping the treadle depressed and moves the workpiece from one impression to another without stopping the hammer. The operator cannot select heavier or lighter blows of the ram without stopping production and resetting the height of the ram at its raised position. Figure 13 is a photograph of a board drop hammer.

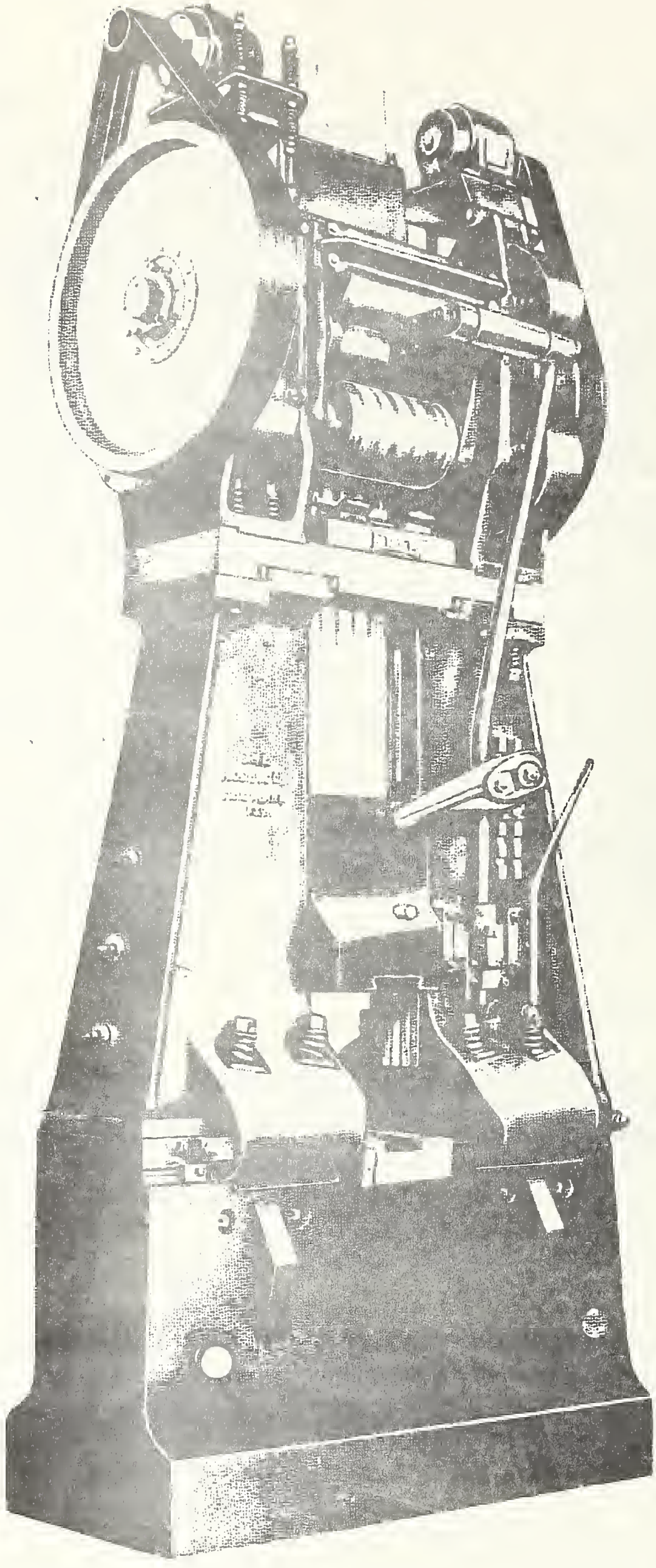
Air lift-gravity drop hammers are similar to board drop hammers in forging principle, size, and types of forgings produced. They differ from board drop types in that the ram is raised by air or steam power.

The major manufacturers of board drop and air lift-gravity drop hammers are Chambersburg and Erie Foundry Company. The automobile industry generally uses hammers rated from 2,000 to 6,000 pounds costing $50,000 to $145,000.

Power Drop Hammers

Power drop hammers are the most powerful machines in general use for the production of impression die forgings by impact pressure. They differ in principle from gravity drop hammers in that steam (or air) under pressure of 90 to 125 psi supplements the force of gravity in the downward stroke and creates a higher striking velocity. The power drop hammer is equipped with a foor-operated treadle board for regulating the force of the blow.

An important advantage of the power drop hammer is that the operator can totally control the striking force. A disadvantage is the destructive effect the tremendous force of the hammer has upon itself. As the magnitude of



Source: Erie Foundry Company

FIGURE 13
A Board Drop Hammer

the impact force increases, there is a concomitant increase in the hammer's self-destruction. The hammer's life is considered infinite but certain parts wear out frequently because of the severe impact forces.

The major manufacturers of power drop hammers are Chambersburg, Erie and Ajax Manufacturing. Auto parts are predominantly manufactured from 3000-6,000 pound hammers with occasional use of hammers up to 12,000 pounds. Prices for a 3,000 and 6,000 pound hammer are $200,000 and $275,000 respectively. These hammers will require one, two or three operators depending on the size and intricacy of the forging being made and produce about three forgings an hour.

8.5.3 Forging Presses

Forging presses employ a squeezing action as opposed to an impact action characteristic of hammers. Only impression die presses are used in the automotive industry. Advantages of presses over hammers are:

- Rates of production are higher and, therefore, there is less operator cost per part.
- The press dies can be less massive, hence less tool steel is required because presses deliver less impact than hammers.
- Presses require less operator skill than hammers.
- More intricate and precise forgings can be made.

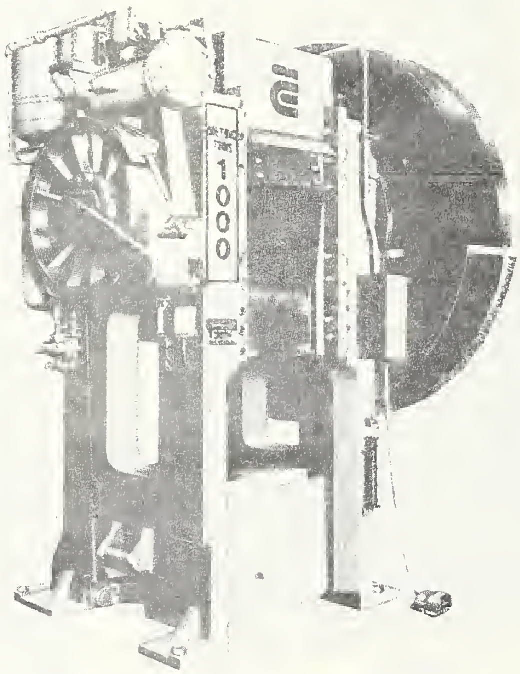
Some disadvantages of presses compared to hammers are:

- Presses require a higher initial investment—as much as three times the cost of a hammer that will produce the same forging.
- Presses are less suitable for forging asymmetrical workpieces.
- Presses are less suitable for thin forgings and deep webbed parts.

Three principal types of presses are the mechanical, hydraulic and screw presses. They are distinguished by their delivery of power.

Mechanical presses are used most often in manufacturing automotive parts. Figure 14 shows a mechanical press from Erie Press Systems. Mechanical presses utilize a motor driven full eccentric type of drive shaft that imparts a constant-length stroke to a vertical ram. They generate forces ranging from 300 to 8,000 tons. Because the ram stroke of a mechanical press is shorter than the strokes of a hammer or hydraulic press, they are best suited for low profile forgings.

The major manufacturers of mechanical forge presses are Erie Press Systems, National Machinery, Ajax Manufacturing, Verson Allsteel, and Hill-Acme. Mechanical presses used for forging automobile parts range in size from 300 to 12,000 tons and range in price from $200,000 to $2,000,000. An additional $50,000 to $75,000 must be spent by the forge shop to construct a foundation allowing for underneath access to the equipment. Lead time for ordering ranges from ten months to two years.* Production rates are limited by the speed of the operator and are usually about three to five parts per minute. When the equipment is modified with automatic transfer devices, production can be as high as ten parts per minute. For manual operation, one or two operators are needed depending on the size of the forging.



Source: Erie Press Systems

FIGURE 14
Mechanical Forging Press

* The lead time is a function of whether the equipment is custom made or "in stock" with custom made equipment generally averaging about a two-year lead time.

Hydraulic Presses

The ram of a hydraulic press is driven by hydraulic cylinders and pistons, which are part of a high-pressure hydraulic or hydropneumatic system. Capacities for hydraulic presses range from 300 to 50,000 tons. The major advantages of hydraulic presses are:

- Die pressure can be regulated at any point in the stroke.
- Metal deformation rates can be controlled and even varied during the stroke to prevent rupture of the workpiece.
- By the use of split dies, many parts are made with offset flanges, projections, back draft, and other design features that are extremely difficult, if not impossible to incorporate into hammer forgings.

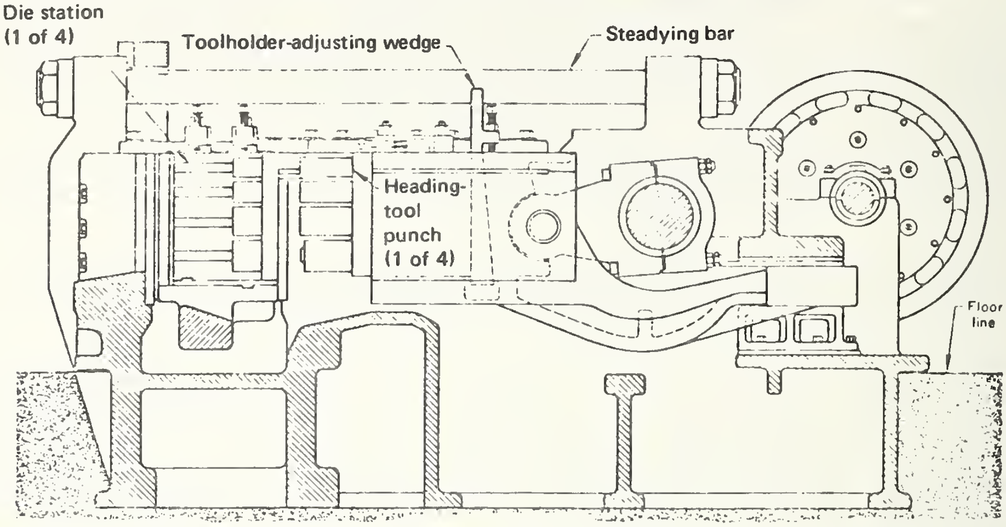
Hydraulic presses are used almost exclusively for open die forging which, as described previously, is not used in manufacturing automotive parts. The cost of this equipment is comparable to the cost of mechanical presses. The manufacturers are the same as the manufacturers of mechanical presses.

Screw Presses

Screw presses will probably be used in increasing numbers to replace hammers which are being scrutinized by OSHA quite closely because of the noise they generate. Screw presses cannot generate true impact loading but can be loaded more rapidly than mechanical and hydraulic presses. At present, there are about 20 screw presses operating in the U.S., but there are no American manufacturers of the presses.

8.5.4 Upsetters

Upset forging machines are basically double-acting, mechanical presses operating in a horizontal plane. Like the mechanical press, they employ a flywheel, air clutch and eccentric shaft to operate the slide (or heading ram), as shown in Figure 15. Upset forging machines are commonly referred to as "headers" because they were originally developed to upset metal for bolt heads and similar shapes. Upsetters are rated in inches based on the largest bolt stem diameter for which it can provide an upset head.



Source: Forging and Casting, Volume 5 of the Metals Handbook

FIGURE 15
Principal Components of a Typical Horizontal Machine for Hot Upset Forging With a Vertical Four-Station Die

The primary manufacturers of hot upsetting equipment are Hill-Acme, National Manufacturing Company and Ajax. Equipment in common use for manufacturing automobile parts requires one operator, is rated from 1 1/4 inch to 7 inches, costs from $120,000 to $680,000 and produces 150 to 400 parts per hour. Forge shops should allow 9 to 14 months for delivery.

8.5.5 Rolls

Roll forging machines or rolls contain two semicylindrical rolls containing shaped grooves. A heated bar of metal is placed between the rolls, and as they revolve, the heated bar is progressively squeezed between them. The equipment accepts stock up to 5 inches in diameter. Depending on the number of passes needed to preshape the stock and the size of the stock, rolls will process 125 to 500 pieces an hour. Typically, rolls are driven by 15 to 75 horsepower motors. They range in cost from $100,000 to $220,000 and have a lead time of 10 to 12 months. Principal manufacturers of roll forging equipment are National Machinery and Ajax.

8.5.6 Support Equipment

In addition to forging and heating equipment, typical forging plants comprise an array of machinery and equipment to perform auxiliary operations such as sizing, trimming, cleaning and inspecting. Auxiliary equipment requirements include:

- Sizing equipment
- Descaling and cleaning equipment
- Trimming equipment
- Finishing equipment
- Inspection equipment.

Each type of equipment is briefly discussed below. Capacity, cycle time, lead times and prices for selected support equipment are shown in Table 5.

Sizing Equipment

The usual forms of stock for forging are bars or billets in lengths up to 20 feet. The three most common types of equipment used to cut these lengths into multiples or blanks are:

- Shears
- Circular and band saws
- Abrasive wheels.

Because of their relative efficiency and economy, shears are widely used for cutting stock of small or intermediate sizes. The vertical shear, with a stationary lower blade and moving upper blade, is most common.

The leading manufacturers of shearing equipment are Hill-Acme and Buffalo Shear. Equipment ranges from simple shears, driven by 5-horsepower motors, which sizes 1/2 inch stock, to 200,000 horsepower shears designed to segment 5-inch stock. Prices range from $10,000 to $300,000 depending on size of stock and production rate.

Automatic materials handling equipment can add another $3,000 to $200,000 to the cost of the system. Production rates vary from 30 pieces per minute to 60 pieces per minute based on the diameter of the stock and the number of bars sheared per stroke.

TABLE 5
Support Equipment for Forging

Equipment	Manufacturers	Capacity	Cycle Time	Lead Time	Price
Cold and Hot Shears[1]	Hill-Acme Buffalo Shear	Smallest stock ½ inch Largest stock 5 inches	6[illegible] pieces min-small stock 30 pieces min-large stock	Some equipment is stock, others up to 1 year	$1[illegible] to $1[illegible]
Trimming Presses[2]	Erie Press U.S.I.-Clearing E.W. Bliss	175 to 300 tons	10 parts per minute	8 to 1[illegible] months	$35,[illegible] to $2[illegible]
Coining Knuckle Press[3]	E.W. Bliss (Division Gulf & Western) U.S.I.-Clearing Minster	250 to 4[illegible] tons	15 to [illegible] strokes per minute, 1 to 4 parts per stroke	1 to 1[illegible] years	$1[illegible] to $1,[illegible]
Abrasion Cleaning Equipment[4]	Wheelabrator Pangborn (Division of Carborundum) Goff Gutman (German)	2 to 9 cubic feet loading capacity	8 to 20 minutes per load	Stock item to 26 weeks	$2[illegible] to $340,000

1 Sizing equipment
2 Trimming equipment
3 Finishing equipment
4 Cleaning equipment

When the stock is not suited for shearing or when flat, square ends are desired, saws or abrasive wheels are commonly used. Extremely hard material is abrasion cut.

Descaling and Cleaning Equipment

The removal of oxide scale prior to forging operations is accomplished by such methods as high velocity water spraying, brushing, or scraping against knives. Removal of scale during hammer forging is achieved by loosening the scale with the striking of the hammer and blowing it off with a high velocity stream of air.

Descaling after forging (referred to as cleaning) is accomplished with abrasive blast equipment. Abrasive blast equipment can be applied to all shapes and sizes of forgings used in the auto industry.

Wheelabrator and the Pangborn Divison of Carborundum dominate the abrasion cleaning equipment industry with approximately 95 percent of the market. Butman(German) Goff and small fabricating shops make the remainder of the equipment. The machines in common use subject the parts to tumbling and blasting of either metal spheres or angular grit.

Equipment load capacities for machines in common use range from 2 to 90 cubic feet and cost between $20,000 and and $340,000. Approximately half the cost of the $340,000 machine would be due to such auxiliary features as a dust collector, automatic loader, noise control, and extra safety switches. A typical plant would probably have abrasive blast machines which cost about $50,000.

Production rates, which range from 8 to 20 minutes per load, are dependent upon the level of cleanliness required and the tenacity of the scale. Scale which has formed from several heat treatments or has been embedded during forging will require longer process time and highly abrasive grit.

Trimming Equipment

Flash or excess metal is removed from forgings on trim presses. Press sizes usually range from 175 to 300 tons for automotive parts. Manufacturers include Erie Press, U.S.I. Clearing and E.W. Bliss. Presses range in price from $95,000 to $200,000 depending on the size of platter.

Finishing Equipment

After heat treating and cleaning, forgings may be finished to closer tolerances by grinding or coining. Coining can be performed in a trim press. In the case of automotive connecting rods, a specialized coining press sizes the parts to tolerances within a few thousandths of an inch. Parts sometimes require a straightening operation to overcome twisting, bending or warping which resulted from trimming, heat treating, cleaning or handling. Three point hydraulic presses can be used for manual straightening. Cylindrical parts such as tubes, axles and shafts are ordinarily straightened in machine rolls when sufficient quantities are involved. Finishing equipment ranges in cost from $100,000 to $1,000,000 depening on the size of the final part. Major manufacturers include E.W. Bliss and U.S.I. Clearing Minster.

Inspection Equipment

Inspection equipment is required at two stages in the forging process:

- Sampling of bar stock as it is received at the forge
- Inspecting the finished steel product.

Incoming steel bundles are checked for hardness on Brinell hardness testing machines. Macrocleanliness is checked by soaking a smooth ground transverse face of a sample in a hot bath of 10 percent nitric acid solution and inspecting the resultant surface visually.

Final products may be inspected for physical characteristics, internal integrity, tensile strength or fatigue, depending upon the specifications of the buyer. Equipment for all of these testing procedures is seldom found in typical forging plants. Most of the small shops are equipped to inspect for physical characteristics and surface flaws only.*

8.5.7 Automatic Forging Equipment

As the availability of skilled workers decreases and labor costs rise, forging plants are considering automatic forging equipment such as the system shown in Figure 16.

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* Inspection equipment is relatively cheap, however. A hardness tester, acid heating unit, and magnetic particle inspection machine combined, for example, would only cost about $10,000. Those three pieces of equipment would essentially be all the inspection equipment which would be needed. A major supplier of this equipment is Magnaflux.

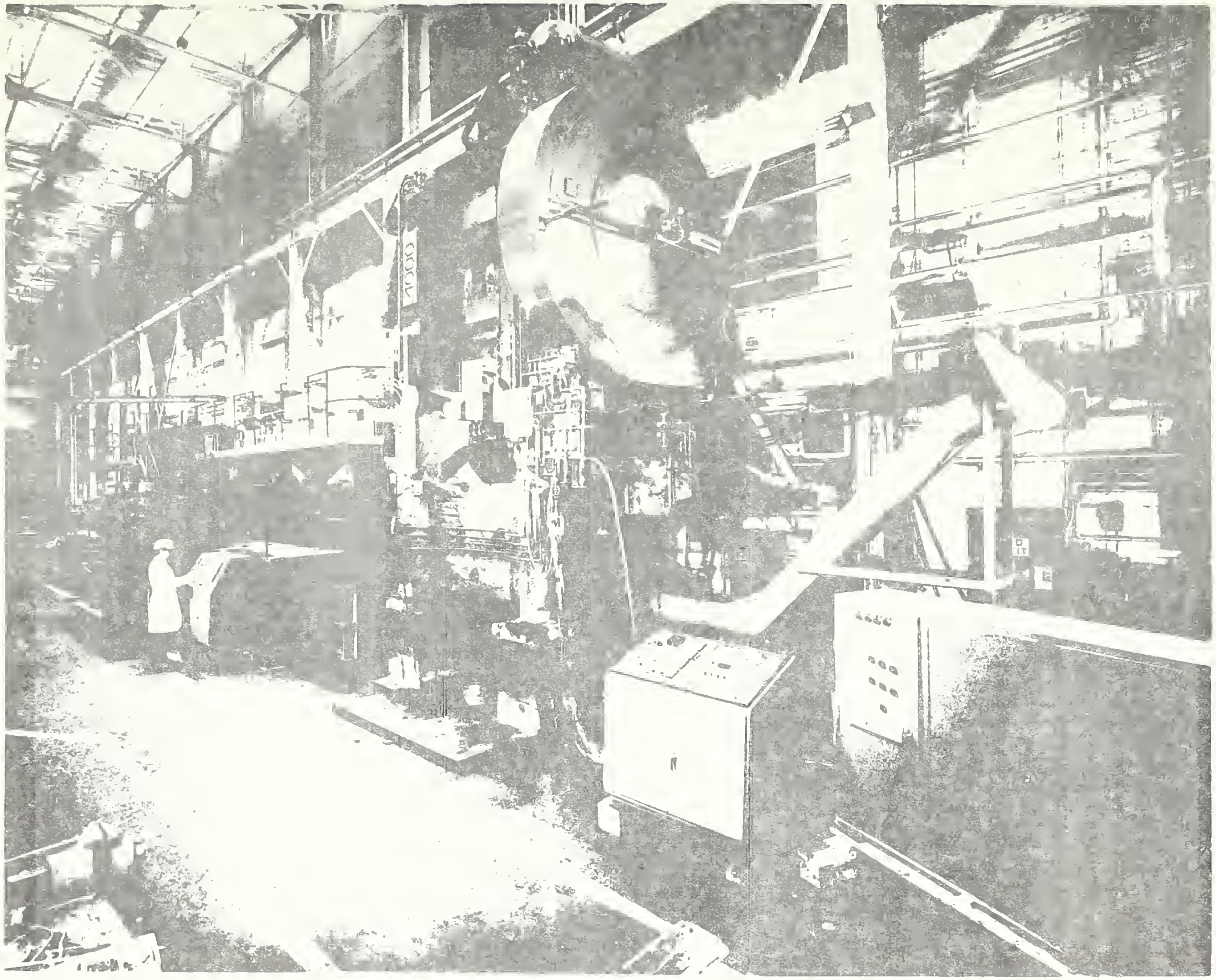

FIGURE 16
Automatic Forging System

Automatic forging equipment combines into one integrated operation the following functions:

- Bar bundle conveying and unscrambling
- Bar feeding
- Billet shearing
- Weight inspection
- Heating
- Billet temperature checking and loading
- Roll preforming
- Die lubrication
- Forge pressing and transfer
- Coining and trimming
- All handling external to the machine.

Manufacturers of this type of equipment include Amforge-Hasenclever, Ajax Manufacturing, Chambersburg Engineering, Erie Press Systems, National Machinery, Verson Allsteel Press and Hatebur. Equipment prices range from $1 to $2 1/4 million for the manufacture of small parts and $6 to $10 million for the manufacture of large parts. Twelve to fourteen months lead time is required for the equipment.

Automotive parts currently being produced in automatic forging machines include ball joint sockets, front wheel drive components, gear blanks, nuts, pinions, radiator plugs, universal joint flanges and wheel hubs. A typical production rate for producing front-wheel drive hubs and spindles is 600 parts per hour using a 4,000 ton press which requires one operator. The minimum production needed for a profitable run is approximately 25,000 units for large parts and 100,000 on small parts. Economies are possible on high volume production because of high material savings and reduced labor and machining.

8.6 SIZE AND STRUCTURE OF THE HOT FORGING INDUSTRY

The entire forging industry is quite varied. Large captive forge shops can employ more than 600 people and use many presses or hammers. Some small shops employ less than 10 people and are really closer to blacksmith shops. The Forging Industry Association has counted 500 to 600 commercial, or non-captive shops. Of these, approximately 250 are considered to be viable, modern automated forging facilities.

Forge shops have tended to cluster in certain locations due to the crucial role of die design in the forge process.

Dies wear out after 20,000 to 50,000 impressions and, depending on output rate, this can occur in less than 30 hours. Thus forge shops are constantly in need of new dies. Important forging centers have the manpower and facilities to supply forge shop needs. Key centers include Lansing, Michigan; Toledo and Cleveland, Ohio; and Pittsburgh, Pennsylvania. Many forging facilities are tied closely to machine shops located nearby.

8.6.1 Automobile Industry and Commercial Forge Shops

Of the $2.2 million sales of the commercial or non-captive hot forging industry in 1978,* 7.4 percent went to passenger cars and parts and another 18.4 percent went to trucks, buses, trailers and related parts. Off-highway equipment accounted for another 13.8 percent. So, while motor vehicles together account for 40 percent of all commercial hot forgings, only 19 percent of this is for passenger cars. (See Table 6.)

Thirty percent of the commercial forge shops are estimated to send a significant portion of their production to the auto industry. Important independent forge shops include Columbus Forge, Columbus, Ohio; Atlas Forge, Lansing, Michigan; Wyman and Gorman, Worcester, Massachusetts; and Pittsburgh Forgings, Coraopolis, Pennsylvania. The commercial automotive forge shops tend to be medium to large-sized shops, employing 100 to 400 people.

8.6.2 Automobile Industry Captive Forge Shops

The importance of the auto industry in forging is quite large. It is estimated that the captive auto forge shops by themselves forged as much as the entire commercial forging industry in 1978. Thus, approximately 80 percent of automotive forgings are done in captive shops. The captive shops tend to do high volume, standard weight forgings. Commercial shops tend to do runs under 500 per day, or pieces under 5 pounds or over 25 pounds. Truck parts thus are often done outside. The auto industry, in its attempts to build lightweight cars, is moving away from interchangeability of truck and car parts. This may create more short-run truck part jobs for commercial forge shops.

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* This does not include cold forgings, but cold forging commercial volume is quite small.

TABLE 6
Annual Report of Commercial Hot Forging Sales
By End-Use Markets
1978
Impression Die Forging Industry

MAJOR END-USE MARKET	Industry Sales Dollar Volume	% of Ind. Sales
1. Farm Machinery and Equipment	$ 106,218,000	4.9 %
2. Aircraft:		
(a) Aircraft Engines and Engine Parts	$ 236,280,000	10.9 %
(b) Aircraft, Aircraft Parts and Auxiliary Equipment	$ 234,112,000	10.8 %
(c) Guided Missiles, Space Vehicles and Parts	$ 30,348,000	1.4 %
3. Automotive:		
(a) Passenger Cars and Parts	$ 160,410,000	7.4 %
(b) Trucks, Buses, Trailers, and Related Parts	$ 398,857,000	18.4 %
4. Internal Combustion Engines (Stationary)	$ 28,180,000	1.3 %
5. Metalworking and Special Industry Machinery	$ 52,025,000	2.4 %
6. Mechanical Power Transmission Equipment incl. Bearings	$ 43,354,000	2.0 %
7. Fabricated Plate Work, Special Industry Machinery	$ 21,677,000	1.0 %
8. Off-Highway Equipment (Construction, Mining and Materials Handling)	$ 299,143,000	13.8 %
9. Ordnance (except missiles)	$ 58,528,000	2.7 %
10. Oil Field Machinery and Equipment	$ 62,863,000	2.9 %
11. Plumbing Fixtures, Valves and Fittings	$ 95,379,000	4.4 %
12. Pumps and Compressors	$ 13,006,000	0.6 %
13. Railroad Equipment	$ 97,547,000	4.5 %
14. Refrigeration, Air Conditioning, and Heating	$ 15,174,000	0.7 %
15. Steam Engines and Turbines (except Locomotives)	$ 41,186,000	1.9 %
16. Other	$ 173,416,000	8.0 %
TOTALS	$2,167,703,000	100.0%

(This report does not include: (1) shipments of aircraft engine blades and buckets from specialized shops devoted primarily to that work; or (2) products forged at temperatures below 300°F.)

Source: FORGING INDUSTRY ASSOCIATION

8.7 TYPICAL PLANT

This section describes a typical forging plant. The plant forges 1 million idler arms per year and has 24 employees. Total capital investment for the plant is $4-5 million, approximately $3 million for equipment and $1-2 million for the building and land.

8.7.1 Plant Layout

A schematic diagram of a typical impression die hot forging plant is presented in Figure 17. As shown, the plant is laid out rectangularly, with materials flowing logically from one process area to the next. In addition to forging equipment, the plant contains an office and rooms for inspection, equipment maintenance, tools, and die storage. A substantial yard is required near the loading docks for the movement of steel carrying trucks.

8.7.2 Materials Flow

The principal materials which flow through the forging plant are steel stock and forged parts.

Steel Stock

As bundles of steel bars are delivered to the yard, representative samples of the steel are tested for hardness and macrocleanliness. Following preliminary tests, the actual manufacturing begins. Bundles of 1 9/32 inch steel stock are hoisted by a fork lift and placed onto the bed of a set of power feed rollers. A laborer unbundles the material. The transfer bed advances the material to the 250-ton cold shear which sizes five bars at a time to 10 1/2-inch lengths. With a cycle time of 12 seconds the equipment sizes 60 pieces per minute.

A bin of sized stock is transferred by fork lift to the automatic feeding apparatus associated with the induction furnace. Stock flows through the furnace in single file and is heated to forging temperature (2175-2250 °F) in 48 seconds. Output from the furnace is fed through the roll forger twice and then passed on to the 1600-ton mechanical press.

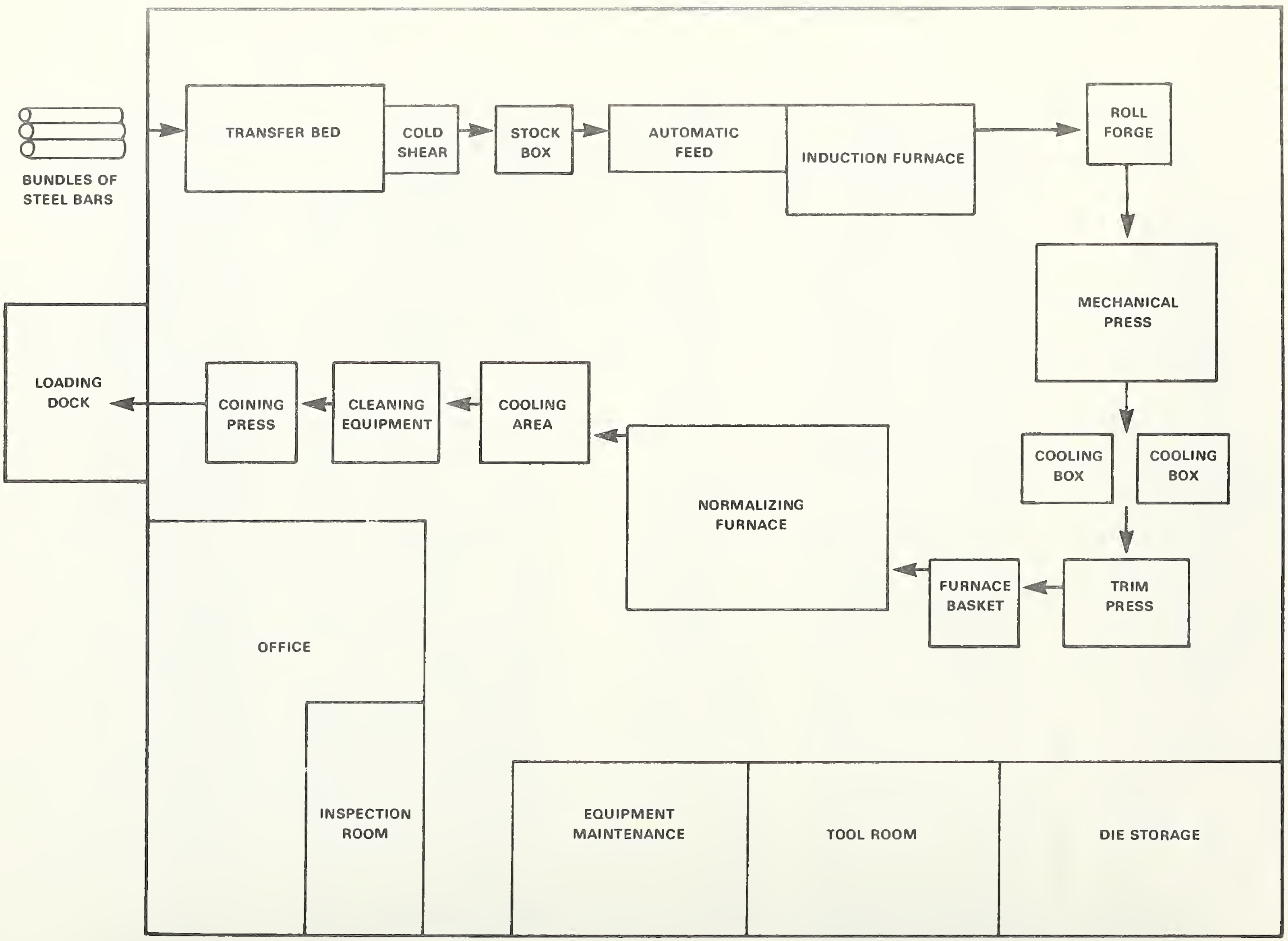

FIGURE 17
Typical Hot Forging Plant Layout

During the press forging operation, the workpiece is passed to sequential cavities in the die block by automatic transfer equipment. The equipment produces one platter* for every two upstrokes. The production rate is 250 platters per hour, that is, 500 finished parts.

Forged Parts

The forgings are cold trimmed one at a time in a 150-ton press after they have been allowed to cool to below 300° F in cooling bins. The operator trims one part out of the platter and then turns the platter end for end to trim the other part out. The parts fall into furnace baskets which are charged into the gas-fired, atmosphere-controlled normalizing furnace. The material is held at temperature for one hour and then air cooled. It then is fed into a tumbling type abrasion cleaner which handles a batch of 100 parts every 12 minutes. After cleaning, the parts are coined to assure straightness and dimensional tolerance. Prior to shipping, a sampling of parts made from each batch of steel is inspected by magnetic particle methods for surface imperfections.

8.7.3 Capital Requirements

Total capital requirements for a small, independent hot forging plant are estimated to range from 5 to 7 million dollars. Building and land costs for a structural steel building with a reinforced foundation are estimated at $1 million and $150,000 respectively. Equipment costs are estimated at $3 million.

Building and Land

The hot forging plant shown in Figure 19 requires a 20,000-square foot building constructed of structural steel with cement block walls. The principal architectural aspect of the building is a reinforced foundation to support the heavy forging equipment.

Location of the plant should be near a freight railroad. Five acres of land is sufficient for a plant of this size. Building costs are estimated at $1 million and land costs are estimated at $150,000. Total building and land costs are shown in Table 7.

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* A platter is the entire workpiece upon which the forging equipment performs work including the flash, tonghold, and as many forgings as are made at one time.

TABLE 7
Building and Land Requirements

Capital Requirement	Cost (Thousands)
Building (20,000 sq ft at $50/sq ft)	$1,000
Land (5 acres at $30,000)	150
TOTAL	$1,150

Equipment

Equipment requirements are summarized in Table 8. Types of equipment include an induction furnace, mechanical press, roll forge, coining press, cold shear, bar transfer bed and various support equipment. Fork lift trucks for a plant of this size would be leased rather than purchased. Total equipment costs are estimated at $3 million.

TABLE 8
Equipment Requirements for a Typical Forging Plant

Equipment	Number	Unit Price (Thousands)	Total Price (Thousands)
Furnaces:			
Induction Furnace including Feeder	1	$1,000	$1,000
Normalizing Furnace	1	300	300
Presses:			
Mechanical Press	1	900	900
Roll Forge	1	200	200
Coining Press	1	200	200
Sizing:			
Cold Shear	1	150	150
Cleaning and Inspecting:			
Abrasion-type cleaner	1	30	30
Magnetic Particle Inspection Equipment	1	50	50
Miscellaneous			
Bar Transfer Bed	1	50	50
Tools, Equipment Gauges		20	20
Bins, Storage and Transporting Equipment		20	20
			$2,920

8.7.4 Labor Requirements

Total labor requirements for a single shift hot forging plant are shown in Table 9. The 24 employees include a plant manager, foreman, two millwrights, a tool and die maker, an equipment mechanic and 18 machine operators and laborers.

TABLE 9
Labor Requirements

Skill	Number
Plant manager	1
Foreman	1
Shipping and receiving clerk	1
Fork lift operators	3
Shear press operator	1
Induction furnace operator	1
Roll forge operator	1
Mechanical press operator	1
Trim press operator	1
Normalizing furnace operator	1
Abrasion cleaner operator	1
Coining press operator	1
Equipment mechanic	1
Millwrights	2
Tool and die maker	1
General laborers	3
Inspectors	3
TOTAL	24

8.7.5 Energy Requirements

The major energy requirements in a hot forge shop are determined by the energy needed to heat steel to forging temperature. This is approximately 350-500 kwh per ton with induction heating. The energy requirements for presses and other forging equipment are small compared to this. It is estimated that a medium size forging plant would require 10-50 kwh per ton for the presses. Thus, a plant forging 1,500 pounds of parts per hour (producing 1,200 pounds of good parts per hour) would require about 500 kw of power.

Heat treating would also require significant amounts of energy. Hardening requires 200-300 kwh per ton of output and tempering requires another 60 kwh per ton of output. Thus, a quench and temper forging operation would require about 850 kwh per ton of output. Space heating requirements would be additional and dependent on plant location.

8.8 KEY ISSUES AND TRENDS

The following describes key issues and trends in the hot forging industry.

8.8.1 Key Issues

The major issues confronting the hot forging industry are:

- Competition from cold forging and powder metallurgy
- OSHA noise levels for workplaces.

Competition from Cold Forging and Powder Metallurgy

One trend to watch is movement away from hot forgings to cold forgings. Cold forging boasts less material waste, reduced machining costs and reduced labor costs compared to hot forging. The limiting factor in cold forging is the high energy requirements. Newer cold forging equipment, however, has the clamping power necessary to make larger parts by cold forging than were previously made.

The use of Powder Metallurgy (P/M) is another potential competition to conventional means of forging automobile parts. At present, there are 8 to 15 pounds of P/M parts in the average automobile in the form of automatic transmission parts and sprockets for camshafts, crankshafts, and water pumps. Additional automotive parts which are candidates for P/M are all gears ranging in size from two inches to nine inches and ranging in weight from 1/2 to 7 pounds. In Germany, Porsche executives are pleased with the cost savings, energy savings and improved fatigue performance being realized with a P/M steel connecting rod. The rod weighs slightly less than 2 pounds and is used in the Porsche 929 V-8.

The powder metallurgy process involves compressing a mixture of metal powder and a lubricant at room temperature in a mechanical or hydraulic press with up to 60 psi to form a green compact material which has a density of 75 to 80 percent. The part is then sintered* at 2,000 to 2,050 F.

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* Heating without melting.

After sintering, the part is considered complete, except for applications requiring greater strength. To increase strength, the sintered part is heat treated to increase density. The chief competitive advantage of the P/M process is reduced cost. A P/M gear can be manufactured with a 30 percent equipment and labor savings over a conventionally forged part.

OSHA Noise Level Limits for Workplaces

Another major issue facing the hot forging industry is noise. The equipment used for hot forging will probably be affected significantly by OSHA's noise level limits for workplaces. At present, hammers are needed for thin webbed and high profiled forgings. In the future, these forgings will probably be made in screw presses which can provide a loading more similar to impacting than other forging presses. At present there are about 20 screw-type presses in the United States; however, there are no manufacturers of such equipment in this country.

8.8.2 Trends

Major trends in the hot forging industry include:

- The trend from eight cylinder engines to four cylinder engines
- Potential for returning to forged crankshafts
- Trend toward induction heating
- Trend toward integrated forging systems.

Trend from Eight Cylinder Engines to Four Cylinder Engines

The 1985 gasoline efficiency requirements for automobiles will make an impact on the forging industry mostly by the use of engines with fewer cylinders and much less significantly by the size reduction of the engine or the size reduction of the car in total.

Unless parts are greatly reduced in size the number of parts per platter incorporated in closed die forging does not change. Likewise, the number of forging strikes necessary for making a part by closed die or upset forging is not greatly influenced by slight reductions in size. Rather, the configuration of the part, which is not likely to change by downsizing, determines the number of forging strikes. The implication of these facts is that the labor and equipment requirements for making automobile parts will not result from their size reduction. There are, however, other trends which will affect the market share of parts made by forging methods.

Potential for Returning to Forged Crankshafts

One potential change which is likely to have an impact on the forging industry in the future is the forging of crankshafts. Ironically, automobile crankshafts were originally forged, and then the industry accepted the cast crankshaft. Now that the industry is weight conscious, there is serious talk of switching back to forged crankshafts because of the superior strength to weight characteristic of forgings.

Trend Toward Induction Heating

Among plants that will continue to operate conventional forging equipment, there is a recognized shift from gas and oil fired furnaces to induction heating. Heating by this apparatus is more efficient, cleaner, more adaptable to automation, and uses less floor space than fuel fired furnaces. The energy is not necessarily cheaper but the availability of energy is more certain.

Trend Towards Integrated Forging Systems

Employment requirements in the forging industry may be affected as the trend toward integrated/automated forging equipment continues. All of the functions necessary for forging can be handled by an integrated system requiring very little monitoring. Thus the operator of an automatic forging machine can theoretically handle all of the functions normally ascribed to five people:

- Sheer press operator
- Induction furnace operator
- Roll forge operator
- Mechanical press or hammer operator
- Trim press operator.

Automatic forging equipment may also obviate the need for some material handling personnel since material handling is completely mechanized with the integrated system.

9. COLD FORGING

9.1 GENERAL

In cold forging, unheated slugs of steel are forced to flow around punches or through shape-forming dies, thus producing shapes of a desired configuration. Such parts require little or no subsequent machining.

During cold forging the temperature of the metal is increased due to friction. However, it never reaches temperatures equivalent to those in hot forging, and work hardening always occurs. The improved physical properties (high tensile and yield strength) resulting from cold forging are retained in the finished parts unless they are subsequently heat treated.

Cold forging differs from most other metal-working processes in that the metal is always being pushed in compression and seldom pulled in tension. Because of this, the metal can be deformed more drastically with less chance of cracking or tearing.

Steel is the only metal used for the cold forging of automotive parts. Components which are cold forged include spark plug bodies, hydraulic valve lifters, steering ball joints and power steering shafts. Cold forging boasts less material waste, reduced machining costs and reduced labor costs compared to hot forging. Cold forging presses require more energy than hot forging presses, but a significant net energy savings is realized because no heating is required. The future trend in forging is toward greater use of cold forging of all types of auto parts requiring high strengths.

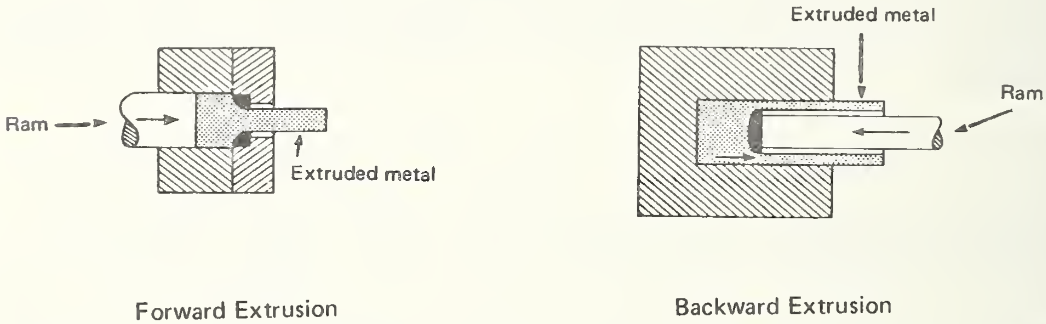
9.2 MAJOR TYPES OF COLD FORGING

The principle types of cold forging used in the manufacture of automotive parts are:

- Cold extrusion
- Cold upset forging
- Coining.

9.2.1 Cold Extrusion

In the process of cold extrusion*, metal is forced to flow through a die orifice in either a forward or backward direction. In forward extrusion, the metal flows in the same direction in which the energy is being applied. In backward extrusion, the metal flows in the reverse direction in which the energy is being applied. In the latter case, the metal usually follows the contour of the punch or moving die. Figure 1 gives a visual comparison of forward and backward extrusion. In combination extrusions, forward and backward extrusions are performed on the part simultaneously.



Source: Manufacturing Materials and Processes, by H.D. Moore and D.R. Kibbey, 1965.

FIGURE 1
Diagram of Forward and Backward Extrusion

Cold extrusion is performed in a mechanical press which exerts compressive force on a pre-sized section of bar stock (slug) which has previously been annealed and coated with zinc phosphate and a lubricant. Subsequent to cold extrusion, little or no machining is necessary. Spark plug bodies, engine valves and hydraulic valve lifters are examples of automotive parts which are manufactured by cold extrusion.

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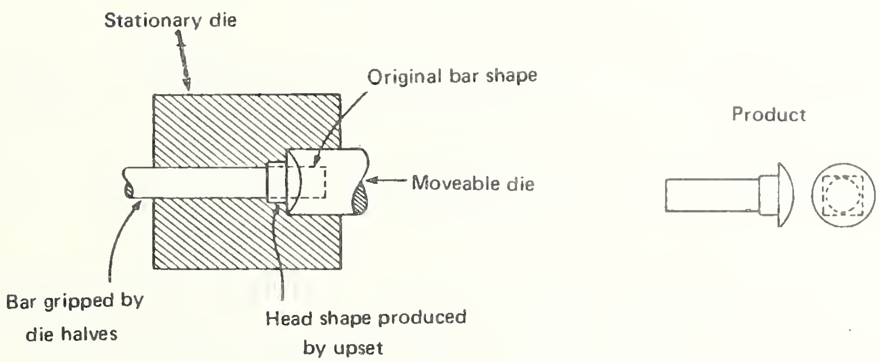
* Often called "cold forming."

9.2.2 Cold Upset Forging

Cold upset forging is similar to hot upset forging with two exceptions:

- The metal is not heated.
- A zinc phosphate coating is required on the cold metal to aid lubrication of the piece before processing.

In the upset forging process, a rod is gripped by a stationary die, and the moveable die, containing the cavity of the desired shape, is forced against the protruding part of the rod. The action is one of squeezing pressure rather than hammering action. This process is illustrated in Figure 2.



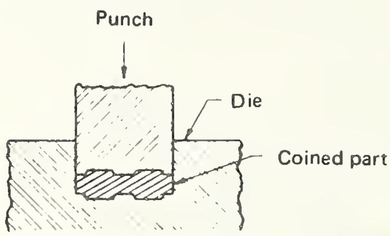
Source: Manufacturing Materials and Processes, by H.D. Moore and D.R. Kibbey, 1965.

FIGURE 2
Cold Upsetting

As in other cold forging processes, the metal stock is annealed, cooled, given a coating of zinc phosphate and lubricated before it is placed in the upsetting press. Lubrication is necessary to prevent the metal from sticking to the dies. Steering ball joints, piston pins and alternator pole pieces are often cold upset forged.

9.2.3 Coining

Coining is essentially a sizing operation where pressure is applied to all or some portion of a forging's surface in order to obtain closer tolerances and smoother surfaces. The process, illustrated in Figure 3, is used in producing coins and medals and in numerous other cases where exact size and fine detail must be obtained. Coining may be used either before or after extrusion.



Source: Materials and Processes in Manufacturing, by E.P. DeGarmo, 1974.

FIGURE 3
The Coining Process

As a preliminary operation to extrusion, coining is used to produce closer dimensions on slugs sheared or cut from commercially cold drawn steel bars. The process is necessary so that the slugs will have a proper fit with the extruding die. Slugs that do not fit closely in a backward extruding die often produce non-symmetrical parts and may cause punch breakage because of non-concentric centering within the cavity.

Following extrusion, coining may be used to confirm the final dimensional qualities of a part that has been processed by cold extrusion or hot impression die forging. Hot forged connecting rods and cold extruded steering linkage parts are examples of components that are coined as a finishing operation.

9.2.4 Metals Used

At present, steel is the only metal that is used for cold forged automotive components. Of the other metals that are competitively priced, none offer the strength that is required in automotive forging applications.

Carbon and alloy contents of steel which are practical for cold forging are limited. The carbon content of plain carbon steel must be no greater than 0.35 percent for backward extrusions, for example, and no greater than 0.60 percent for forward extrusions. Other limitations in alloy contents for extrusion are shown in Table 1. Steels with alloy contents above these levels are impractical to extrude.

TABLE 1
Practical Limits to Alloying Contents
for Cold Forged Steel

Element	Percent by Weight
Silicon	.5
Manganese	1.5
Nickel	1.0
Chromium	.9
Molybdenum	.4

Source: Impact Machining, by Verson Allsteel Press Company, 1969.

9.3 ADVANTAGES AND DISADVANTAGES OF COLD FORGING

Automotive products can be made by cold forging at a lesser cost than hot forging because there is little or no wasted material and considerably less energy cost. The major disadvantage of cold forging is that it is restricted to uniform and symmetrically shaped parts.

Advantages of cold forging are:

- Higher tensile strength and yield strength than with hot forging can be obtained from the same grade of material.

- Cold forging uses less energy than either casting or hot forging because the metal does not have to be melted or heated. Furnace temperatures for the annealing processes required in cold forging are only 1750-1850°F, compared with 2150-2350°F for heating the metal as in hot forging.

- No machining of a cold forged part is required due to the excellent cold forging surface finish. Thus, there is little or no wasted material.* Verson Allsteel Press Company experienced a 57 percent reduction in material requirements with the use of cold forging compared with hot forging for the manufacture of valve bodies.

Disadvantages of cold forging are:

- High carbon and alloy steels are not practical for cold forging. These materials have very high yield strengths; thus, tremendous pressures are required to deform them.

- Production of asymmetrical shapes is not recommended for cold forging because non-uniform pressures on the dies can cause them to crack. Consequently, cold forged parts tend to be solid or hollow rounds, squares or hexagons.

9.4 AUTOMOTIVE APPLICATIONS OF COLD FORGING

In recent years there has been a trend toward increased use of cold forging for the manufacture of auto parts in recognition of the cost savings which are possible with this process. Parts which are presently cold forged are of three types:

- Parts which previously were machined from bar stock in automatic screw machines

- Parts which previously were hot forged

- New parts which have no manufacturing history.

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* A typical surface finish on a cold forging is 32 microinches for an outer surface and 8 microinches for an inner surface.

Parts which are relatively new to the U.S. automobile include many front wheel drive components. Table 2 lists parts which are typically made by cold forging. The location of selected cold forged parts on the automobile is shown in Figure 4.

TABLE 2
Selected Automotive Applications of Cold Forging

Cold Forging Process	Automotive Components
Extrusion	Spark plug bodies, hydraulic valve lifters, engine valves, shafts, steering linkages
Upsetting	Piston pins, steering ball joints, power steering parts (shaft, gears, etc.), alternator pole pieces
Coining	Rotors, hot forged connecting rods, cold extruded steering linkages

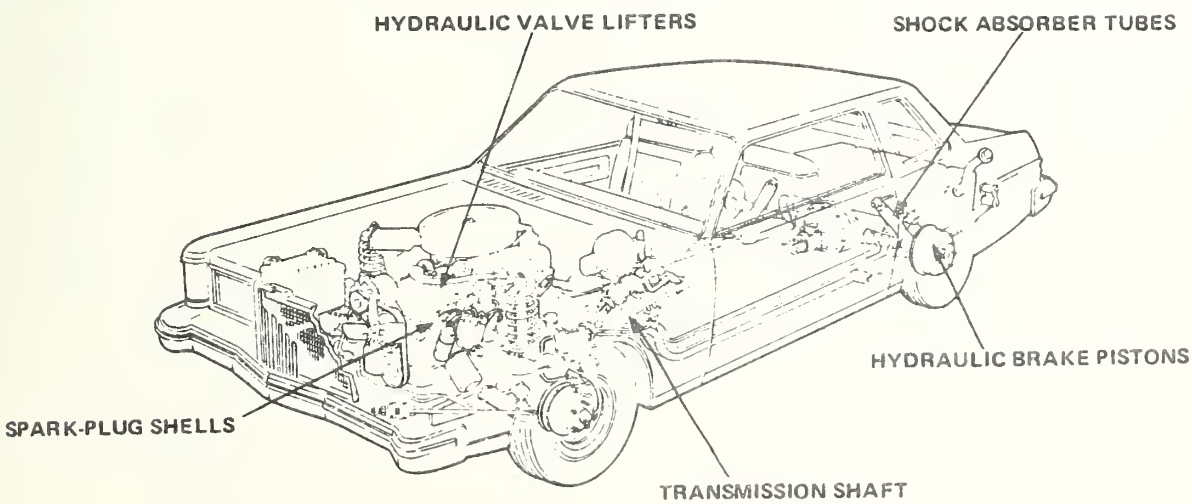

FIGURE 4
Automotive Applications of Cold Forging

9.5 EQUIPMENT REQUIRED

Six principal types of equipment are required for cold forging:*

- Sizing equipment
- Annealing furnaces
- Phosphate coating and lubricating equipment
- Mechanical presses
- Hydraulic presses
- Upsetters.

Each is described below.

9.5.1 Sizing Equipment

Two types of sizing equipment are used for cold forging:

- Cold shears
- Slug headers.

As in hot forging, steel bars must be sheared into suitable lengths before forging. The cold shear is used for cutting the steel to the proper stock lengths, called slugs. Following shearing, a slug header is required to alter the size or shape of the slugs so they will fit smoothly into the forging presses. Figure 5 gives an illustration of a slug shearing and heading process. Detailed information on sizing machines is provided in Table 3.

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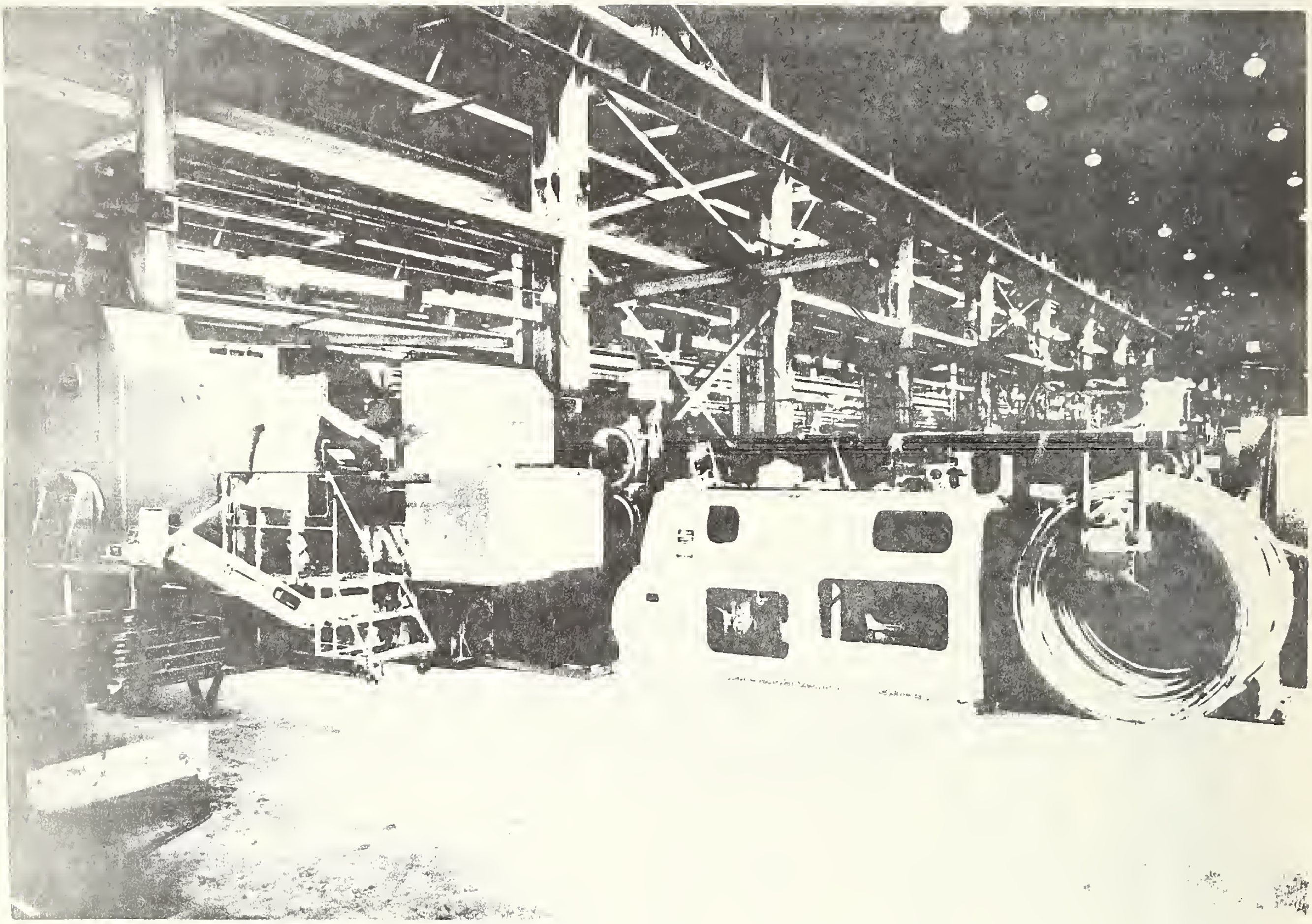
* As in hot forging, dies would also be needed. Die cost is a function of die complexity and size. For example, a 24" x 24" x 12" die block cut with an impression for making connecting rods would cost approximately $5,000. The life of dies ranges from 20,000 to 50,000 parts produced.

TABLE 3
Sizing, Annealing, and Phosphating and Lubricating Equipment for Cold Forging

EQUIPMENT	MANUFACTURERS	CAPACITY	CYCLE TIME	LEAD TIME	PRICE
Cold Shear	Waterbury Farrel Hill Acme Buffalo Shear	From 100 to 500 tons	60 pieces/min-small stock 30 pieces/min-large stock	Some equipment is stock, others up to 1 year	$ 50,000 to $150,000
Slug Header	National Machinery Waterbury Farrel	3/4" diameter	180-200 pieces/min	8 - 12 mos.	$230,000
	Peltzer Ehler (Germany) Nalmedie (Germany)	1" diameter	150-160 pieces/min	8 - 12 mos.	$375,000
Annealing Furnace	Holcraft Sunbeam Surface Combustion Ipsen	500 to 5,000 lbs/hr	12 hours	8 - 12 mos.	$170,000-$500,000
Phosphating and Lubricating Equipment	Stevens Van Winkle		25-70 minutes		$200,000 - $1,500,000



Source: Waterbury Farrel Division of Textron

FIGURE 5
Steel Coils Being Sheared and Slug Headed

Cold Shears

Cold shears are used for fast, efficient and low cost reduction of steel bars to slugs. The ends of each slug must be cut squarely and have a minimum of distortion. Overlaps and loose or ragged metal cannot be tolerated because of the problems they would cause in subsequent forging operations. The best slugs are made by high velocity shearing machines to avoid pinching of the metal. Capacities of cold shears range from 100 to 500 tons. Leading manufacturers are the Waterbury Farrel Division of Textron, Hill Acme and Buffalo Shear. Some cold shears are readily available in stock while others may require up to 12 months. Cold shear prices range from $50,000 to $150,000. Further information on cold shears is shown in Table 3.

Slug Headers

Slug headers are used after shearing for two purposes:

- To alter the size or shape of slugs so they fit more closely in the extrusion die
- To produce desired indentations on the ends, or bevels on the edges, of the slug.

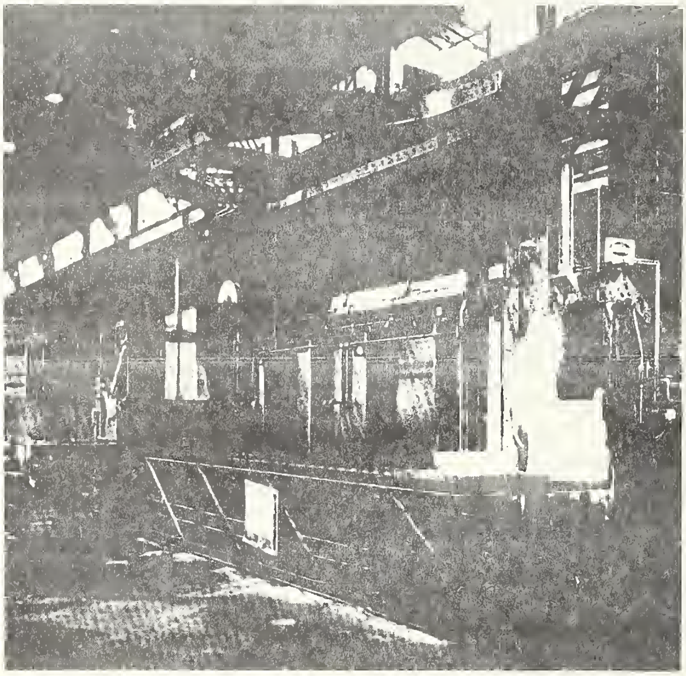
When producing indentations and/or bevels on a slug, the slug heading machine is essentially replacing machining operations.

Slug headers range in price from $230,000 for a machine capable of heading 3/4" diameter steel bars to $375,000 for a machine capable of heading 1" diameter steel bars. Leading manufacturers are National Machinery and Waterbury Farrel of the U.S., and Peltzer Ehler and Nalmedie of Germany. Further details are listed in Table 3.

9.5.2 Annealing Furnaces

Annealing furnaces are batch operated and of the same designs used for post heat treating of castings. Annealing is required after heading of slugs. Annealing is also performed as an intermediate step between extrusions when considerable cold deformation has occurred.

A typical annealing furnace is shown in Figure 6. Manufacturers include Sunbeam, Holcraft, Surface Combustion and Ipsen. Furnace capacities range from 500 to 5,000 pounds and are priced from $170,000 to $500,000. Lead time for a typical annealing furnace is 8 - 12 months.



Source: Sunbeam Equipment Corporation

FIGURE 6
Annealing Furnace

9.5.3 Phosphate Coating and Lubricating Equipment

Phosphate coating and lubricating equipment is required to treat the unheated metal surface prior to cold forging. The phosphate coating acts as a "carrier" for the lubricant. Lubricants are necessary to reduce die wear and to control or improve the uniformity of metal flow.

Typical phosphating and lubricating equipment consists of a series of tanks and a materials handling system for transferring the material between tanks. Generally, there are nine tanks. In sequence, the operations which are performed are: alkali cleaning, hot water rinsing, acid pickling, cold water rinsing, hot water rinsing, zinc phosphate coating, cold water rinse, neutralizing rinse and lubricating.

Phosphating-lubricating systems are manufactured by Stevens and Van Winkle. Prices range from $200,000 for a unit typically used in a job shop and up to $1.5 million for a system appropriate for high volume use by a major auto maker.

9.5.4 Mechanical Presses

All mechanical forging presses have a ram (or slide) that moves in a vertical direction by mechanical means. Different types of mechanical presses are distinguished by the method used to transfer energy to the ram. Mechanical presses which are used in cold forging include:

- Knuckle joint press
- Crankshaft press
- Eccentric gear press.

Knuckle joint presses are primarily used for coining, and crackshaft and eccentric gear presses are only used for extrusion. Detailed information on mechanical presses is summarized in Table 4.

Knuckle Joint Presses

Knuckle joint type presses are principally used for coining and are probably the least desirable for cold extrusion except for the production of shallow parts requiring short strokes.* While such presses permit the economical application of heavy loads and powerful, gradual squeezes, their length of stroke is shorter than that of a standard eccentric or crankshaft type press of equal tonnage rating. Knuckle joint presses are very difficult to automate and few are in fact automated.

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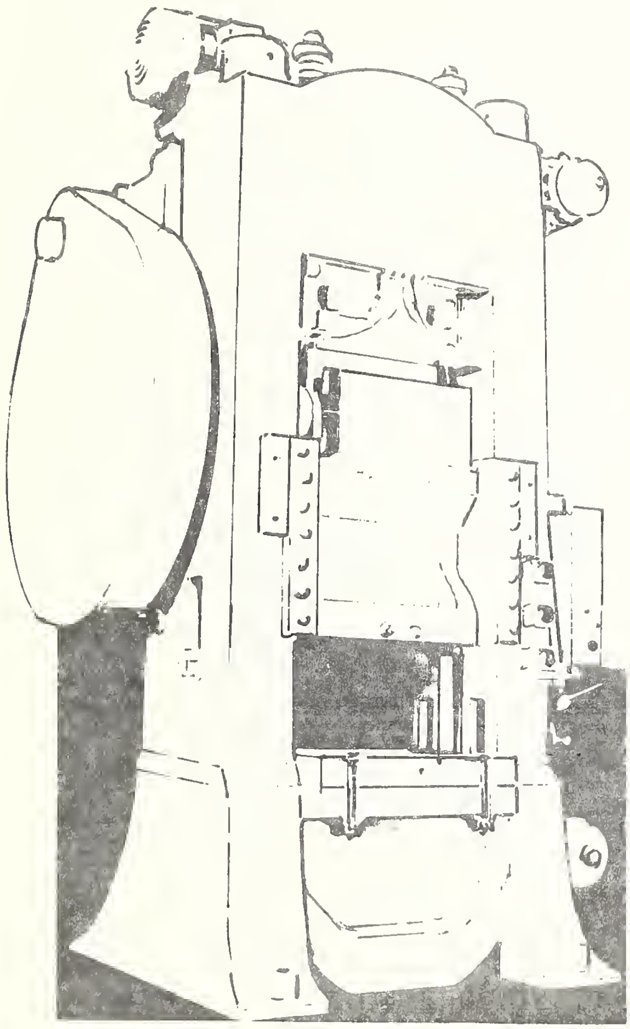
* Knuckle joint presses are also occasionally used in place of a slug header in the manufacture of slugs.

TABLE 4
Cold Forging Presses and Upsetters

EQUIPMENT	MANUFACTURERS	CAPACITY	CYCLE TIME	LEAD TIME	PRICE
Knuckle Joint Press	E.W.Bliss U.S.I. Clearing Minster	250 - 2,000 tons	15 to 20 strokes per minute, 1 to 4 parts per stroke	12 - 15 months	$ 100,000 to $1,000,000
Crankshaft Press	National Ajax	5/8" stock diameter	120 strokes per minute	12 - 18 months	$350,000
Eccentric Gear Press	Hartford Waterbury Farrel	3/4" stock diameter 1 1/2" stock diameter	100 strokes per minute 45 strokes per minute	12 - 18 months 12 - 18 months	$550,000 $1,250,000
Hydraulic Press	Eric Press Systems Mesta Machine E.W.Bliss	300 - 500 tons	Up to 600 strokes/hr	12 months	$400,000 $ 700,000
Upsetters	National Waterbury Farrel	1" stock diameter 1 3/8" stock diameter 1 1/2" stock diameter	80 - 100 pieces per minute 70 pieces per minute 50 pieces per minute	Stock item to 16 months	$400,000 $600,000 $1,000,000

The major manufacturers of knuckle presses are E.W. Bliss (Division of Gulf and Western), U.S.I. Clearing, and Minster. The capacity of these machines ranges from 250 to 2,000 tons and they are priced between $100,000 and $1,000,000. Normally 1 to 1 1/4 years are required for ordering new equipment. A photograph of a typical knuckle press appears in Figure 7.

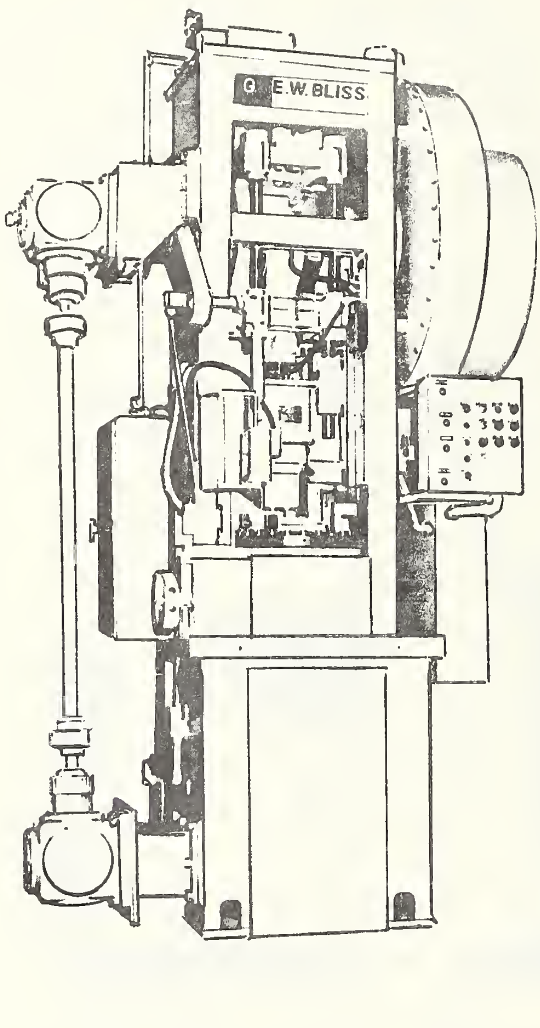


Source: E.W.Bliss Division, Gulf and Western Manufacturing Company.

FIGURE 7
Knuckle Press

Crankshaft and Eccentric Gear Presses

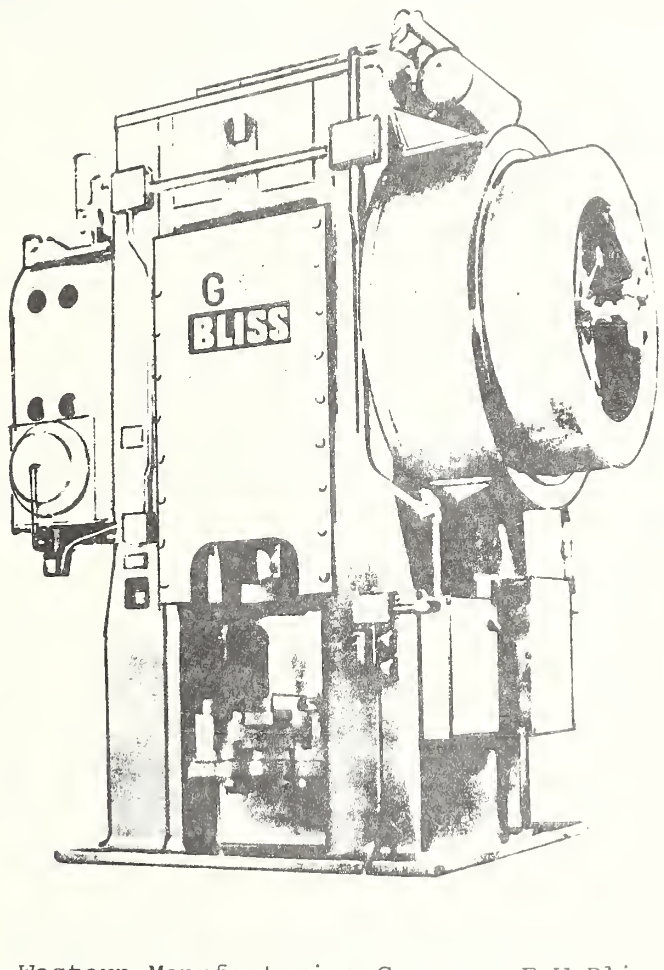
Crankshaft type presses, in which the slide is driven directly by a crankshaft, offer positive and efficient high-speed action because of their simple harmonic motion. They can be of either single or double crank construction. Single crank presses are usually recommended for 25 or more strokes per minute, and double-cranked presses for speeds of less than 25 strokes per minute. The maximum stroke length of both types is 14 inches. A photograph of a typical single crankshaft type press appears in Figure 8.



Source: Gulf & Western Manufacturing Company, E.W.Bliss Division

FIGURE 8
Typical Crankshaft Press

Eccentric gear presses combine some of the best features of both knuckle joint and crankshaft type presses. Heavy pressing forces can be transmitted efficiently and longer strokes are available. These characteristics make the eccentric gear press more appropriate than the knuckle joint or crankshaft type presses for large, long parts such as automobile shafts. A typical eccentric gear press is shown in Figure 9.



Source: Gulf & Western Manufacturing Company, E.W.Bliss Division

FIGURE 9
Eccentric Gear Press

Manufacturers, prices and capacities are the same for both crankshaft and eccentric gear presses. The presses used for cold extruding automotive parts are rated between

200 to 2000 tons and are powered by motors developing 50 to 400 horsepower. Manufacturers include Waterbury, Farrel, Hartford, National Machinery and Ajax. Lead times of 12 to 18 months are usually needed to construct these machines valued at $350,000 to $1,250,000. The long lead times are required because virtually none of these machines are standard. A purchaser must provide parameters such as the following to provide guidance in designing the apparatus:

- Parts to be made
- Production rate
- Materials used.

9.5.5 Hydraulic Presses

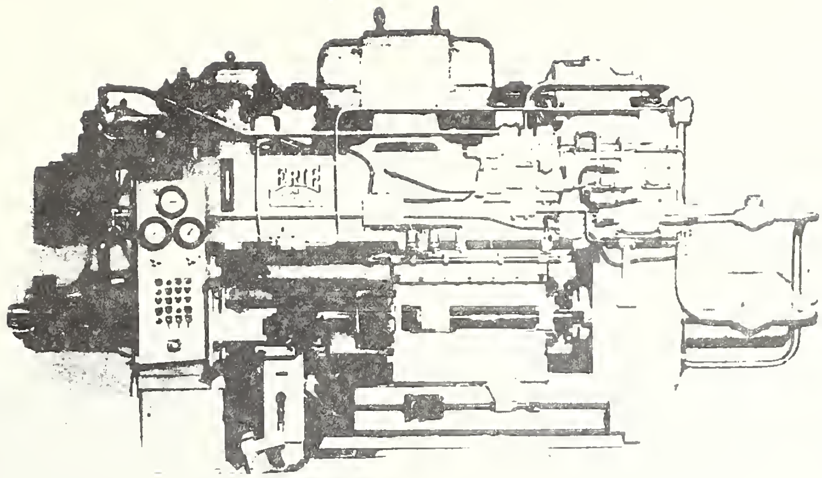
Hydraulic presses are well suited to two types of cold extrusion operations. These are:

- Single die operations where press tonnage is required over a long stroke distance

- Extremely long extrusions such as torsion bars, axle shafts and drive shafts.

A major advantage of hydraulic presses is that they cannot be damaged due to overloading. If an overload condition develops due to a double slug or harder slug being placed in the die cavity, the press will stop, or slow down. Also, there is no mechanical linkage to break, thus providing savings in both original and replacement tooling costs, as well as in maintenance and down-time expenses. A typical hydraulic press is shown in Figure 10.

The initial cost of hydraulic presses is generally lower than mechanical presses of equal tonnage. However, where deep punch penetration and very high pressing forces are required, the operating speed of hydraulic presses is much lower. Also, while hydraulic presses exert high squeezing power, their impact or setting pressure is not as great as those of mechanical presses. They can be used with automatic feeding equipment as long as such equipment is designed to cycle the press, but they are not recommended for completely automated, continuous-cycling type operations.



Source: Erie Press Systems

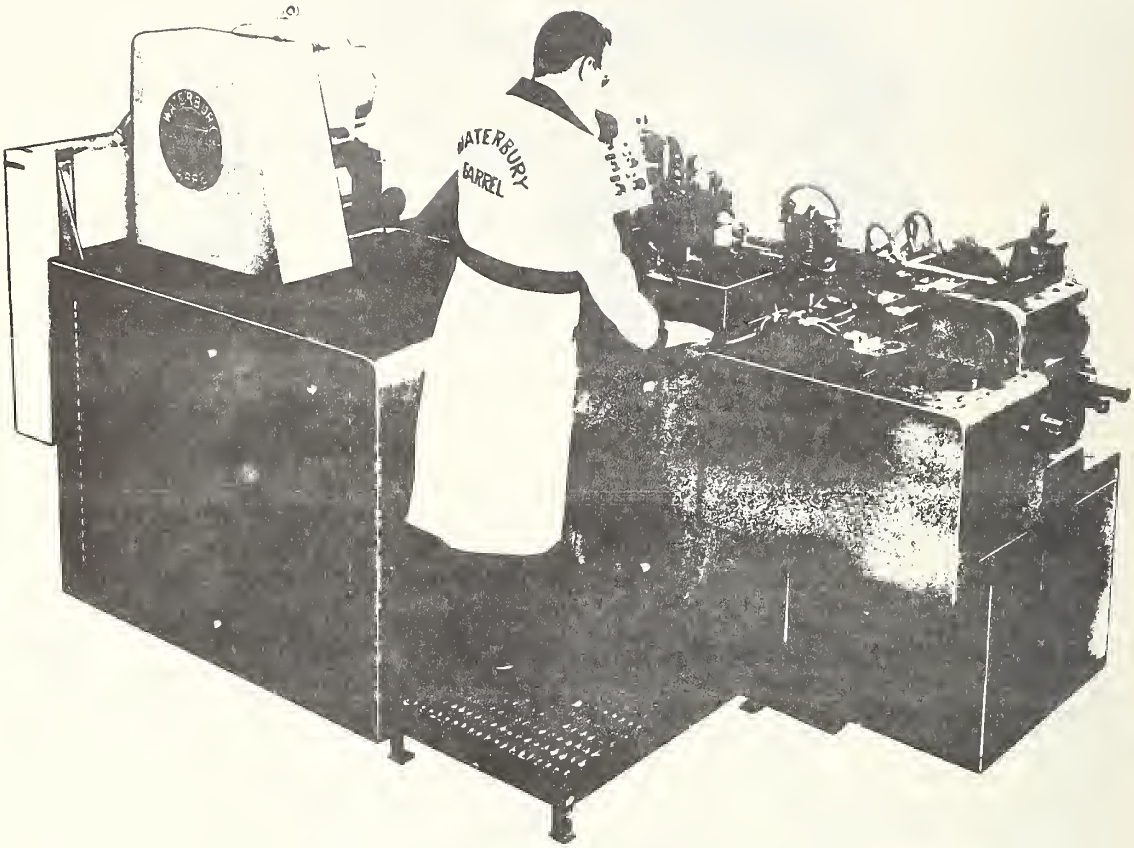
FIGURE 10
Hydraulic Press

Principal manufacturers of hydraulic presses are Erie Press Systems, E.W.Bliss and Mesta Machine. Prices range from $400,000 for a 300 ton press to $700,000 for a 500 ton press. Further details of press cycle times and lead times are provided in Table 4.

9.5.6 Upsetters

Upsetters, or upset forging machines are used in both cold forging and hot forging. They employ a flywheel, air clutch and eccentric shaft to operate the slide (or heading ram). Upset forging machines are commonly referred to as "headers" because they were originally developed to upset metal for bolt heads and similar shapes. A typical upsetter is shown in Figure 11.

The primary manufacturers of upsetters are National Manufacturing Company and Waterbury Farrel. Equipment in common use for manufacturing automobile parts ranges in cost from $400,000 to $1,000,000 and produces 50 to 100 parts per minute. Detailed information on upsetters is provided in Table 4.



Source: Textron, Inc., Waterbury Farrel Division

FIGURE 11
Upsetter (Upset Forging Machine)

9.6 SIZE AND STRUCTURE OF THE COLD FORGING INDUSTRY

The cold forging industry is not a distinctly separate industry. Cold forging processes, for the most part, were introduced by the large manufacturing firms, often as a substitute for machining processes. Thus, cold forge operations are often found integrated into the large machining and manufacturing facilities of the major auto makers. One of the important captive cold forge shops is General Motors' facilities at Saginaw, Michigan.

An estimated eight to ten independent commercial cold forge shops have been established throughout the country that supply parts to the auto industry. These include Braun Engineering in Detroit and Masco Corporation, Taylor, Michigan. Braun claims to be the world's largest independent cold extruder. Ninety-five percent of the company's 1978 revenues of $52.3 million were generated by sales to the auto industry. Braun makes constant velocity joints used with front wheel drive cars and five to six million piston pins per month.

9.7 TYPICAL PLANT

There are only ten commercial cold forging shops serving the automobile industry at present. Thus, cold forging of automotive components is generally performed by large forging facilities operated by the auto manufacturers.

In order to illustrate the requirements for cold forging, the following sections describe the layout, materials flow and estimated capital, labor and energy requirements for a small, independent cold forge plant. It is assumed that the plant produces automotive shaft-type products at a rate of five per minute using two 250-ton horizontal hydraulic presses. Each finished part is assumed to weigh approximately ten pounds.

9.7.1 Plant Layout

The layout for a typical cold forging plant is illustrated in Figure 12. As shown, the plant includes space for two annealing furnaces, a large phosphating and lubricating system, and two cold forging presses. Additional facilities in the plant are rooms for equipment maintenance, die storage, offices and a tool room.

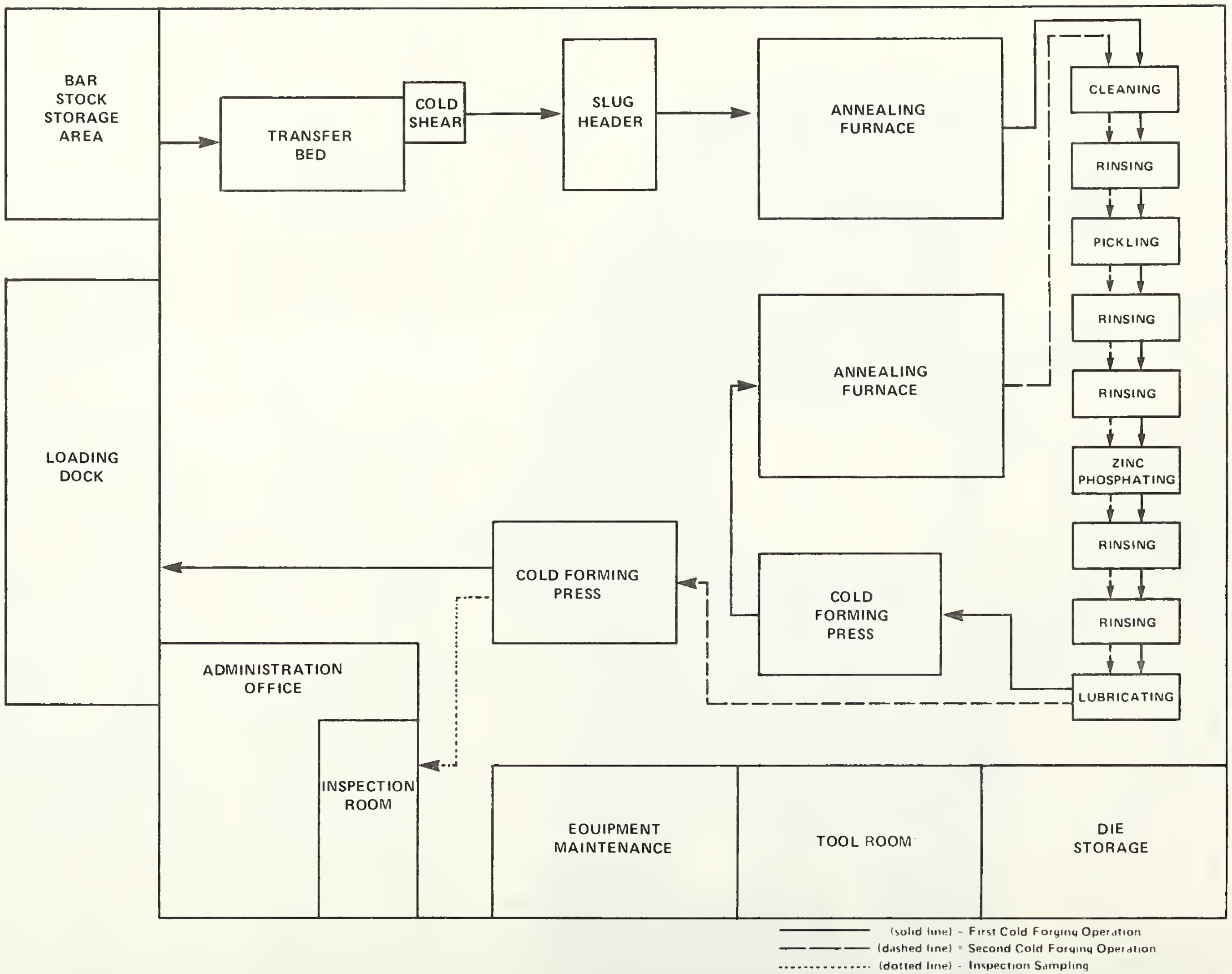


FIGURE 12
Typical Layout of a Cold Forging Plant

9.7.2 Materials Flow

The principal material which flows through the cold forging plant is steel stock.

The flow of material is set in motion by a forklift truck hoisting steel bars onto a transfer bed which in turn advances the material to the cold shear. Automatic transfer equipment included in the price of the slug header delivers material to that machine. Properly shaped slugs are ejected out of the slug header into annealing furnace baskets which are inserted into the furnace. After annealing, the slugs are dumped from the furnace baskets into trays. These trays are carried by an overhead monorail to successive tanks in the phosphating and lubricating system. These tanks sequentially clean, pickle, zinc-phosphate coat and lubricate the slugs.

Each processed tray of lubricated parts is transferred by forklift to the forging press area and dumped into a box out of which the press operator picks up the pieces in turn and loads them into the hydraulic press. The extruded parts are ejected from the press into annealing baskets for the second annealing process. The filled baskets become input to the furnace.

After the second annealing, the parts travel again through the series of tanks which ultimately yields a lubricated product. The logistics of the phosphating/lubricating operation involve an alternating of tank trays filled with slugs not yet extruded and tank trays filled with semi-finished parts which have been through the first extrusion process.

After the second trip through the tanks, the semi-finished parts are taken to the second hydraulic press. Like the first press, this operation consists of two extrusion passes. The machine operates at a rate of ten strokes per minute. Thus, 300 parts are completed per hour. A sampling of parts produced from each batch of steel are inspected for surface flaws using magnetic particle techniques. Following inspection the parts are crated and shipped.

9.7.3 Capital Requirements

Capital requirements for a small, independent cold forging operation making an automobile shaft are estimated at $3 to $3.5 million. Total building and land costs are estimated at $1.15 million, and equipment costs are estimated at $2.1 million.

Building and Land

The cold forging operation may be contained in a large well ventilated rectangular building constructed of structural steel and cinder block. Separate rooms in the building are for die storage, tools, maintenance, inspection and administrative offices. Building dimensions are approximately 100' by 200'.

Location of the plant should be near high-speed transportation that can convey the finished parts to the auto assembly plants. Five acres of land is sufficient for a plant of this size. Building costs are estimated at $1 million and land costs are estimated at $150,000. Total building and land costs are shown in Table 5.

TABLE 5
Building and Land Requirements

Capital Requirements	Cost (Thousands)
Building (20,000 sq ft at $50/sq ft)	$ 1,000
Land (5 acres at $30,000/ acre)	150
TOTAL	$ 1,150

Equipment Requirements

Equipment requirements are summarized in Table 6. Types of equipment required include sizing equipment, annealing furnaces, a phosphating lubricating system, hydraulic extrusion presses and miscellaneous baskets, trays, inspection and transfer equipment and miscellaneous tools. Two fork lift trucks for this plant would be leased. Total equipment costs are estimated at approximately $2.1 million.

TABLE 6

Equipment Requirements for a Typical Cold Forging Plant

Equipment	Number	Unit Price (Thousands)	Total Price (Thousands)
Sizing:			
Cold Shear	1	$ 100	$ 100
Slug Header	1	375	375
Annealing:			
Furnaces	2	200	400
Phosphating/Lubricating:			
Phosphating/Lubricating System	1	300	300
Presses:			
Hydraulic Extrusion Presses	2	400	800
Miscellaneous:			
Baskets, Trays		20	20
Magnetic Particle Inspection System	1	50	50
Bar Transfer Bed	1	50	50
Tools, Gauges		20	20
TOTAL			$2,115

9.7.4 Labor Requirements

Labor requirements for a single shift cold forging plant are shown in Table 7. The 18 employees include a plant manager, foreman, mechanic, tool and die maker and operators for the various forging and annealing machines.

TABLE 7
Labor Requirements

Labor Category	Number
Plant Manager	1
Foreman	1
Shipping and receiving clerk	1
Fork lift operators	2
Shear press operator	1
Slug header operator	1
Furnace operator	1
Coating tanks operator	1
Extrusion press operators	2
Mechanic	1
Millwright	1
Tool and die maker	1
Inspectors	2
General laborers	2
TOTAL	18

9.7.5 Energy Requirements

A cold forged plant does not require an initial heating before pressing. Thus energy is used chiefly by the plant's headers and presses and any heat treating furnaces. Energy use for annealing and tempering would be 200 - 300 kwh/ton and 60 kwh/ton respectively as in hot forging. If annealing is required, the furnace energy use can be the most significant in the plant.

Energy use for presses expressed per ton of metal processed would vary greatly depending on the part being made. The power requirements for metal deformation in cold forging are approximately four times greater than the amount required for hot forging. However, deformation as a percent of total part volume varies considerably from part to part. For hot forging, it is estimated that a typical part would require 10 - 50 kwh per ton for pressing. In cold forging, the same part would require 40 - 200 kwh per ton.

The typical plant described in this section is assumed to produce 1.5 tons/hr using two extruders operating at 75 hp (56 kw) and one slug header operating at 50 hp (37.5 kw). Total energy use for the presses is thus 150 kw. Two annealing operations add about 200 kwh per ton each for a combined 750 kw of power for the entire forging operation. Additional energy costs for the plant would be incurred for space heating. This amount would depend on the plant location.

9.8 KEY ISSUES/TRENDS

Key issues/trends which are affecting the cold forging industry are:

- Increased usage of front wheel drive
- Experiments with warm forging
- Technological advances in cold forging materials.

9.8.1 Increased Use of Front Wheel Drive

It is estimated that 50 to 95 percent of North American built cars will utilize front wheel drive by 1985. Presently, constant velocity joints used in front wheel drive transaxles are exclusively manufactured by cold extrusion. Examples of new cars that will incorporate front wheel drive include the General Motors "X" car, the 1981 Ford Erika, and 1982 models of Ford's Pinto and Bobcat.

9.8.2 Experiments with Warm Forging

A technology which is actively being researched is warm forging, a manufacturing technique much like cold forging except that the slug is heated at temperatures as high as 1200° F. In some cases, the temperature of the workpiece is above the material's recrystallaization temperature and therefore technically hot forging, but the equipment used is the same that is used for cold forging and so therefore, it is considered an offshoot of cold forging. Also, the material is still hundreds of degrees below the lower critical temperature in the case of steel and not subject to the problems of heavy sealing.

Advantages of warm forging compared to cold forging include:

- No zinc phosphating or lubricating is needed
- No annealing is needed prior to forging
- Twenty-five to fifty percent less pressure is needed for deformation.

The capital investment which would be required for a cold forging shop to begin warm forging operations is solely an induction heater used to heat the slug prior to forging. Parts presently being made by warm forging include steering sector gears and differential side gears.

9.8.3 Technological Advances in Cold Forging Materials

Technological advances which could increase the application of cold forging include cleaner steel, higher temperature lubricants and higher strength tool steels.

- Cleaner steel. Any impurity in steel can cause the rupturing of the slug under extremely severe deformation. By producing "cleaner steel," higher rates of deformation will be allowed. Common impurities are slag, sulfides and silicates which are normal byproducts of the steelmaking process.
- High temperature lubricants. Present lubricants lose efficiency about 400° F. By developing lubricants that can withstand 600° - 1400°F., higher production rates of cold forging would be possible.

- Higher strength tool steels. Cold forging places tremendous impact loading on the die tools. Current tools can shatter when they are being used to forge relatively high strength slugs. Stronger, more impact resistant tool steels are needed before alloy steels presently considered too strong and deformation resistant can be cold forged.

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